This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

Google books

https://books.google.com

83

AVIATION FIRE CONTROL TECHNICIAN 3

NAVY
TRAINING
COURSES

AVIATION
FIRE CONTROL
TECHNICIAN 3

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10388

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1957

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

623.5
Un34a

PREFACE

This Navy Training Course was written to serve as an aid for enlisted men of the U. S. Navy and the U. S. Naval Reserve who are preparing for advancement to the rate of Aviation Fire Control Technician 3. The content of this course presupposes a knowledge of basic electricity. You can get this by studying the text *Basic Electricity*, NavPers 10086, which should be done prior to working on this course. A reading list is provided which, if followed, will enable the striker to acquire a better background for study in the field of aviation fire control. Combined with the necessary practical experience, a thorough study of the materials contained in this course will assist the striker in preparing for examinations for advancement in rating.

This course provides information concerning the theory of fire control, aircraft computing and noncomputing sights, armament control systems, aircraft turrets, and bomb directors.

Aviation Fire Control Technician 3 has been prepared jointly by the U. S. Navy Training Publications Center, Memphis, Tennessee, and the Training Division of the Bureau of Naval Personnel. Credit also is given to the Naval Air Weapons Systems School, Jacksonville, Florida, for their technical review and for the preparation of the end-of-chapter questions which review the materials contained in each chapter.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

<table>
<tr><th>REQUIREMENTS*</th><th>E1 to E2</th><th>E2 to E3</th><th>E3 to E4</th><th>E4 to E5</th><th>E5 to E6</th><th>E6 to E7A</th></tr>
<tr><td>SERVICE</td><td>4 mos. service—or completion of recruit training.</td><td>6 mos. as E–2 or 8 mos. total service.</td><td>6 mos. as E–3 or 14 mos. total service.</td><td>12 mos. as E–4.</td><td>12 mos. as E–5; total service at least 36 mos.</td><td>36 mos. as E–6.</td></tr>
<tr><td>SCHOOL</td><td>Recruit Training.</td><td></td><td>Class A for PR3, PRS3.</td><td></td><td>Class B for MN1.</td><td>Class B for AGCA, MNCA, MUCA.</td></tr>
<tr><td>ENLISTED PERFORMANCE EVALUATION</td><td colspan="2">As used by CO when approving advancement.</td><td colspan="4">Counts toward performance factor credit in advancement multiple.</td></tr>
<tr><td>PRACTICAL FACTORS</td><td colspan="2">Locally prepared check-offs.</td><td colspan="4">Records of Practical Factors, NavPers 760, must be completed for all PO advancements.</td></tr>
<tr><td>PERFORMANCE TEST</td><td colspan="2"></td><td colspan="4">Specified ratings must complete applicable performance tests before taking examinations.</td></tr>
<tr><td>EXAMINATIONS</td><td colspan="2">Locally prepared tests.</td><td colspan="4">Service-wide examinations required for all PO advancements.</td></tr>
<tr><td>NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)</td><td></td><td colspan="5">Required for E–3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.</td></tr>
<tr><td rowspan="2">AUTHORIZATION</td><td colspan="2">Commanding Officer</td><td colspan="3">U. S. Naval Examining Center</td><td>BuPers</td></tr>
<tr><td colspan="6">TARS are advanced to fill vacancies and must be approved by district commandants or CNARESTRA.</td></tr>
</table>

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48 12 NON-DRILLING	9 mos. 9 mos. 12 mos.	9 mos. 15 mos. 24 mos.	15 mos. 21 mos. 24 mos.	18 mos. 24 mos. 36 mos.	24 mos. 36 mos. 48 mos.	36 mos. 42 mos. 48 mos.
DRILLS ATTENDED IN GRADE#	48 24 12	27 16 8	27 16 13	45 27 18	54 32 20	72 42 32	108 64 38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48 12 NON-DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days 14 days	14 days 28 days 14 days	28 days 42 days 28 days	42 days 42 days 28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

READING LIST

NAVY TRAINING COURSES

Blueprint Reading and Sketching, NavPers 10077–A
Basic Hand Tool Skills, NavPers 10085
Basic Electricity, NavPers 10086

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Correspondence

Number	Title
CC 290	*Physics I*
CB 781	*Fundamentals of Electricity*

Self-Teaching

MC 290	*Physics I*
MB 781	*Fundamentals of Electricity*

* "Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

CONTENTS

Chapter — Page

1. Introduction to aviation fire control — 1
2. Ballistics and trajectory factors — 24
3. The fire control problem — 61
4. Aircraft noncomputing sights — 116
5. Aircraft computing sights — 188
6. Armament control systems — 249
7. Aircraft turret control — 309
8. Bomb directors — 347
9. Electrical equipment — 391
10. Electrical maintenance — 446
11. Mechanical maintenance — 490
12. Boresighting — 537
13. Safety precautions — 555
14. Publications, reports, logs, and forms — 569

Appendix

I. Electrical symbols — 593
II. Mechanical symbols — 595
III. Aviation fire control symbols — 596
IV. AN nomenclature system — 598
V. Answers to quizzes — 604
VI. Qualifications for advancement in rating — 609

Index — 625

STUDY GUIDE

The table below indicates the chapters of this course which particularly apply to your rate. In using this table you should also refer to appendix V and see the exact qualifications required of you.

If you are in an EMERGENCY SERVICE RATING, AQF or AQB, you will be required to complete the chapters noted in the respective columns below.

Chapter	AQ	AQF	AQB
1	1	1	1
2	2	pp. 24–28, 46–55	pp. 28–46
3	3	pp. 61–97	pp. 98–111
4	4	4	pp. 116–139
5	5	5	----------
6	6	6	----------
7	7	7	----------
8	8	8	8
9	9	9	9
10	10	10	10
11	11	pp. 517–532	11
12	12	12	----------
13	13	13	13
14	14	14	14

AVIATION FIRE CONTROL
TECHNICIAN 3

CHAPTER 1

INTRODUCTION TO AVIATION FIRE CONTROL

Although the Aviation Fire Control Technician rating is relatively new, the use of the principles upon which fire control is based is as old as the history of man. When prehistoric man downed a fleeing animal by aiming his rock sufficiently ahead of the beast to cause the rock to intercept the animal, he solved a crude fire control problem. Today when the pilot of a supersonic jet aims his rockets the proper distance ahead of his intended target, he, too, utilizes the same principles. The details of these principles and their application to aircraft fire control equipment are the purpose of this course.

What is meant by aviation fire control? Basically, aviation or aircraft fire control is the applied science of continuously positioning an aircraft, its guns, or launchers, to permit delivery of its weapons effectively against enemy targets. Weapons as we know them today, include guns and ammunition, rockets, bombs, mines, torpedoes, and guided missles.

Any equipment used specifically to assist the pilot, bombardier, or gunner to bring the aircraft, guns, or launchers to bear in proper relation to a target, is considered to be aircraft fire control equipment. This category of equipment ranges from the simple ring-and-bead sights to the amazingly complex electronic, electromechanical devices capable of computing the correct lead in a fraction of a second.

HISTORY

Probably the first delivery of a weapon by air occurred in 1849 when the Austrians were besieging Venice. Time bombs were attached to paper balloons and the wind blew them over the city at an altitude of about 30 feet. They accomplished little material damage, but their effect on morale was great.

History indicates that the first aircraft to deliver a weapon was when an Italian aircraft dropped bombs during a campaign in Tripoli in 1911. Again in 1913 records indicate that the Spaniards dropped bombs in Morocco.

During World War I, planes were first used for observation. Then on 30 August 1914 the Germans dropped a few bombs on Paris and immediately other nations began to use aircraft bombing. The bombs were, of course, dropped in a general area, no attempt being made to achieve pinpoint accuracy. Shortly thereafter, both the Allied Nations and Germany began outfitting their aircraft with guns. With these innovations, the requirement for solving the fire control problem was established.

Of course, the first equipments to solve the problem were extremely crude and were merely optical instruments. But, as each new weapon for aircraft was developed, a new sight or fire control device had to be furnished.

When guns were first placed in aircraft, the ring-and-bead sights were the same as the ones used on surface equipment. These sights established the necessary leads or windage to hit the target. In sighting it was necessary for the pilot to make allowance for or ignore plane speed, target motion, winds, ballistic factors, or gravity. Thus the pilot, as the ancient hunter before him, was the computer that solved the fire control problem.

In the years between World Wars I and II, there was little advance in aviation fire control equipment. The beginning of World War II found Navy aircraft using the ring-and-bead sight. Among the reasons for this lack of development are: Radar and other electronic devices were still in the development stages, surface systems were unusable because of weight and space considerations, and speeds of aircraft had not increased appreciably.

With the advent of the second war, the increased speed of aircraft and the development of electronic and optical devices gave momentum to the designing and procurement of the equipment we know today.

During World War II, the British designed a lead-computing sight that calculated the necessary lead and accounted for many of the problems that the pilot previously had to solve. Because of the type of ranging employed and the neglect of gravity drop, this sight was limited to an effective range of 2,400 feet.

The addition of a radar range solution relieved the pilot of the ranging task, but the lack of a gravity drop solution still curtailed the sight's effectiveness. Accordingly, systems were designed to improve the effectiveness of the fire control. Today there exist air intercept systems capable of detecting, tracking, and computing the correct firing angle for a target under all weather conditions.

Historically, as far as the Navy is concerned, gunner operated systems have closely followed those used in forward firing, and each step in the development of forward firing equipment saw its counterpart in flexible gunnery. The Lewis caliber .30 drum type automatic gun with a rate of fire of 600 to 800 rounds per minutes was the first automatic weapon to be used in combat aircraft. (See fig. 1–1.) Aerial gunnery has come a long way from the Lewis gun mounted on a Scarff ring to the modern uninhabited turrets found on present Navy attack and patrol planes.

The development of bombing equipment repeats the story of steady improvements in the bombsights of World War I to the now famous Norden Mark XV, which saw operational use during World War II by both the Navy and the Army Air Force. With the coming of radar, bombing through overcast, or where the target was optically invisible, became a possibility. Accordingly, a completely automatic radar presentation system was designed. Today's bomb director provides for high altitude bombing from the large carrier attack type aircraft.

Although all level bombing systems provide for target motion, there is no record of a successful high level attack on a maneuvering ship. As a result, dive, toss, and loft

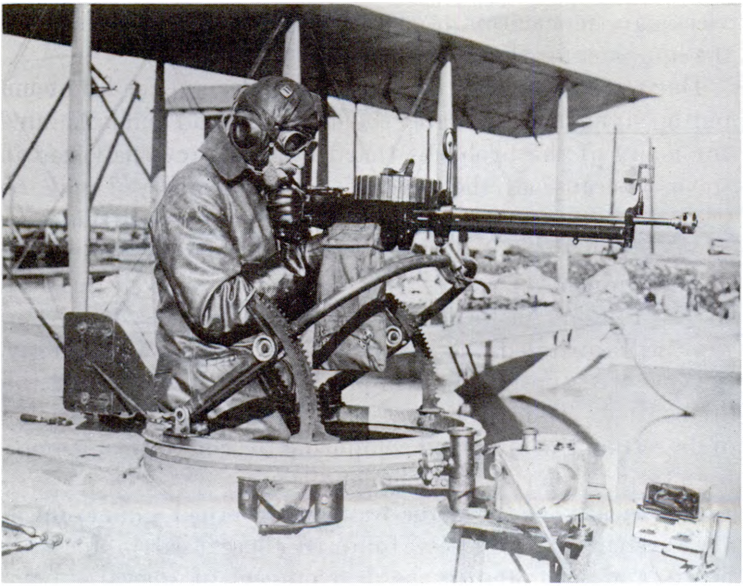


Figure 1–1.—Early version of Navy fire control equipment.

bombing techniques and equipments were developed to reduce the time available to surface craft to avoid being hit.

BUREAU RESPONSIBILITIES

Responsibility for all aircraft armament and ordnance equipment is divided between the Bureau of Aeronautics and the Bureau of Ordnance. It is important for you to know the difference between the two types of equipment and the bureau responsible for each. You need to know the correct terminology to avoid misunderstandings and to aid you when seeking information for any particular equipment.

Briefly, the Bureau of Aeronautics has cognizance over all items of aircraft ARMAMENT which includes fire control equipment, turret control systems, radars, aircraft sights, sighting systems, computers, etc. A detailed discussion of the types of aviation armament equipment is found in the *Bureau of Aeronautics Manual*, NavAer 00–25–500. Armament directives should be consulted frequently for equipment listing and their status.

The Bureau of Ordnance has cognizance over all items of aircraft ORDNANCE equipment which includes guns, ammunition, stores, etc. A detailed discussion of the types of aviation ordnance equipment is found in the *Bureau of Ordnance Manual.* As an Aviation Fire Control Technician, you will be working with aviation armament but should have a good knowledge of related ordnance, its effects, and relationships.

TERMINOLOGY

It has been often said that one of the most difficult parts of learning electronics is the terminology. This is also true of aircraft fire control. In this field there exist many similarities in names and many terms which are undoubtedly strange to the beginner. Therefore, it is highly recommended that you study carefully each new term, name, or expression you encounter. Examples of the terminology that will be necessary for you to understand are ARMAMENT CONTROL SYSTEM and AIRCRAFT FIRE CONTROL SYSTEM. Armament Control Systems are identified by the "Aero" system of nomenclature used by the Bureau of Aeronautics. Armament Control Systems use radar for ranging. Aircraft Fire Control Systems, which are identified by the "Mark, Mod" nomenclature used by the Bureau of Ordnance, are electro-mechanical-optical sighting devices. Some Armament Control Systems contain an Aircraft Fire Control System, but both are aviation fire control equipment. Details of the differences between the two are given in chapters 5 and 6 of this course. Although some aviation fire control equipments (AFCS, etc.) were developed by BuOrd, the cognizance over ALL aviation fire control equipment NOW is exercised by BuAer. This change of control will probably result in some change terminology for NEW systems.

RESPONSIBILITIES AND IMPORTANCE OF WORK

Battles on land and sea, with few exceptions, have been won by the forces capable of delivering the heaviest firepower over the longest ranges for any sustained period. Because the airplane could extend the range by hundreds of miles, it became the most decisive weapon of World War II. Ordnance experts are of the opinion that superior firepower enabled the United States planes to win every combat in the air. An example of our force's superiority was during the famous Mariana's "turkey shoot" when the ratio of losses was 22 to 1. In Korea, while the tactical situation was much different, this ability was further graphically demonstrated.

To be effective, heavier firepower must be accompanied by accurate fire control. With the increased speeds of modern aircraft, aiming devices to aid the pilots and gunners are mandatory. Here is where the Aviation Fire Control Technician enters the picture. These fire control devices must be properly serviced and adjusted to fulfill their assigned tasks. The importance of this work cannot be overemphasized.

It is highly conceivable that some of the equipment you maintain will become the spearhead of the first line of defense. The success or failure of most naval aircraft missions may well depend to a large degree upon the operation of the fire control equipment. How well this equipment performs is dependent upon the knowledge and skill of the Aviation Fire Control Technicians. To become a good Aviation Fire Control Technician, many hours of work and study will be required. This NAVY TRAINING COURSE can help you to become a good technician, but neither this nor any other course can completely train you for your job. You will mainly learn by doing.

DUTIES AND RESPONSIBILITIES

As Aviation Fire Control Technicians, you will be responsible for the maintenance and repair of a wide variety of aviation fire control equipment including equipment associated with intercept, radar controlled turrets, and bombing systems. The degree of this responsibility and the level of complexity of the maintenance will depend upon your rate. Besides the occupational or professional duties, you will have certain military duties as do all ratings in the Navy. These military duties constitute such duties as the manning of battle stations, watch duties, and other assignments related to the requirements for naval operations, management, and security. This course is concerned with your occupational duties and NOT your military duties.

The AQ rating is a group of jobs which require essentially the same aptitudes, training, experience, skills, and abilities. In these jobs, Aviation Fire Control Technicians test, inspect, clean, lubricate, and perform operational tests and adjustments of sights, bomb directors, armament control systems, and radar controlled turret systems. In the maintenance and repair of this equipment, they remove and reinstall major components and subassemblies. They calibrate, repair, and make performance measurements and computing tests of computers, gyros, optical components, and fire control radars.

In order to insure the proper functioning of their assigned equipment, the AQ's must make a detailed analysis of mechanical. electrical, and electronic failures. They must also boresight and aline sights, computers, fire control radars, and aircraft weapons. Further, they are required to make authorized repairs and adjustments to associated test equipment.

As you know, a technician's rate indicates his pay grade and also the level of his aptitude, experience, knowledge, skill, and responsibility. Advancement in the rating is dependent on meeting certain military and professional requirements which are listed in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised). The occupational requirements for AQ3 forms the basis for this course.

It should be pointed out that there are two Emergency Service Ratings: AQF (Aircraft Armament Control Systems) and AQB (Bomb Director). The qualifications for advancement in these two ratings are given in appendix V. This appendix also contains the qualifications for the General Service Rating which is the type of rating held by Regular Navy personnel in peacetime. The Emergency Service Rating is the type of rating held by most members of the Naval Reserve and to which Regular Navy personnel would be shifted in wartime as directed by the Chief of Naval Personnel.

To supply more precise information about specific occupational skills within the Navy, a classification coding system has been established. This coding system is designed to supplement the rating structure. A brief examination of this classification system, as it pertains to the AQ, is instructive in that the system contains information concerning duties and responsibilities. For clarity, it should be emphasized that this Navy Job Classification (N. J. C.) applies more to the description of specific jobs or billets than they do to the description of the qualifications for the ratings.

This examination of the system reveals that there are two general and three specific categories within the Aviation Fire Control Technician rating. The two general groupings are the basic technician and the supervisor technician. The three special groupings are the intercept systems technician, the turret control system technician, and the bombing systems technician.

AVIATION FIRE CONTROL TECHNICIAN, BASIC.—As the title would imply, this category is for the man who has a limited knowledge and experience in the field. He works under the close supervision of more experienced technicians. He performs routine duties pertaining to the maintenance and repair of equipment including intercept, turret control, and bombing systems. Further, he conducts operational tests, makes external adjustments, and isolates failures to major components of equipment. He also tests and replaces relays, plugs, jacks, lamps, fuses, switches, electron tubes, cables, and wiring.

To perform the necessary maintenance and repair work, the basic technician must be capable of interpreting schematic diagrams and using hand tools and small power tools. He also must make repairs to mechanical, electrical, and electronic equipment which may involve the use of electrical and electronic test instruments. Finally, his duties require that he remove and reinstall major components and subassemblies.

Aviation Fire Control Technician, Supervisor.—This category is reserved for the accomplished technician who through experience and study is capable of supervising the basic and special groupings. Therefore, he is responsible for supervising the maintenance and repair of a wide variety of aviation fire control equipment including equipment associated with intercept, turret control, and bombing systems. To do this successfully he must plan, schedule, and assign work to obtain optimum use of available time, space, materials, and personnel.

Besides observing work progress, he must instruct personnel in testing, adjusting, alining, calibrating, and repairing of mechanical, electrical, and electronic aviation fire control equipment. Included in a list of this equipment are such types as computers, antenna drives, fire control radars, gyros, optical components, tracking recorders, control units, and indicator units. Of course to be able to instruct in these operations, he must be very familiar with the operation.

To insure optimum performance, proper alinement, and computing accuracy, the supervisor technician has to evaluate repaired, overhauled, or newly installed equipment. He must also analyze boresighting and alinement tests, and when necessary prescribe corrective measures.

Among his clerical duties, he is responsible for the maintenance of equipment histories. He must also prepare job orders, requisitions, and equipment reports. It is apparent that to fulfill these requirements the supervisor must be an experienced and well-qualified technician. He would, therefore, hold one of the higher rates.

Intercept Systems Technician.—The first of three special categories between the basic and supervisor groups to be considered is the intercept systems technician. This technician is responsible for tests, maintenance, and repairs to intercept systems. To do this, he must perform calibration, alinement, and boresighting of aircraft weapon fire control systems. Included in these systems are optical devices, sights, computers, and fire control radars. Further, this technician makes performance measurements and adjustments to bring systems to optimum performance. His tasks also include the making of a detailed casualty analysis and repairs to equipment as indicated by the analysis.

TURRET CONTROL SYSTEM TECHNICIAN.—This technician's duties encompass tests, maintenance, and repairs of fire control components of turret systems to insure proper functioning of the overall system. He also performs a casualty analysis, repairs, and alinement to the equipment. This includes radars, gyros, computers, and other components, such as turret drives and pneumatic systems. These operations are performed to achieve proper functioning of the overall system. To insure optimum performance, proper alinement, and computing accuracy within the entire turret system, he performs boresighting and alinement tests. Further, he maintains equipment histories, and prepares job orders, requisitions, and equipment failure reports.

BOMBING SYSTEMS TECHNICIAN.—The duties of this technician are to test, maintain, and repair all types of bombing systems. He, as the other technicians, must perform calibration, testing, boresighting, alinement, and repair of electrical, electronic, and mechanical equipment. Included in this list of equipment are power supplies, control boxes, gyros, computers, and optical devices. To insure optimum accuracy and performance of the bombing systems, he makes sensitivity and alinement tests. He also prepares job orders, requisitions, and equipment failure reports.

BILLET TYPES AND LOCATIONS

The specific duties of Aviation Fire Control Technicians depend to a great extent upon the type of organization to which they are attached. As an Aviation Fire Control Technician you may be attached to an operating squadron, a service squadron, an air station, or the maintenance division of an aircraft carrier or seaplane tender. AQ's may also be assigned to a training center or to a naval facility engaged in testing and evaluating aviation fire control equipment.

MAINTENANCE.—In order that you will understand the nature of the maintenance at the various activities, the definitions of the types of maintenance, as defined by the Chief of Naval Operations, are included in this section. First, LINE MAINTENANCE is the daily preparation of aircraft for flight. This includes, but is not limited to, preflight and postflight inspections, adjustments, servicing, correction of minor discrepancies, and troubleshooting.

Secondly, HANGAR MAINTENANCE is the routing upkeep of aircraft. It includes, but is not limited to, accomplishment of periodic and special inspections, replacement of components and accessories, and incorporation of specified changes and bulletins.

The final definition, SHOP MAINTENANCE is the specialized maintenance required for aircraft which is beyond the scope of line or hangar maintenance. It is normally the highest level of maintenance performed by the operating forces. It includes, but is not limited to, bench check, test, calibration, modification, and repair of accessories and components; repair of aircraft; manufacture of certain parts; machine work; accomplishment of specified changes and bulletins.

SQUADRON.—The aircraft squadron which is the standard operating unit in naval aviation is composed of a number of assigned aircraft. The total number of aircraft is dependent upon the mission of the squadron. The squadron also contains the necessary personnel for its operation, maintenance, and minor repairs. The number of maintenance personnel will depend to a large degree upon the type of squadron (supported or self-supported) and the type of aircraft.

There are two general types of squadrons. The first is the SUPPORTED SQUADRON. These are the squadrons which perform line and hangar maintenance on their assigned aircraft. These squadrons also perform shop maintenance to maximum practicable extent utilizing facilities provided by the FASRon or ship.

The second general type is the SELF-SUPPORTING SQUADRON. These are usually special mission type squadrons. Included in a list of self-supported squadrons are Airborne Early

Warning squadrons and Composite squadrons. This type of squadron consists of aircraft, flight crews, maintenance personnel, material and equipment sufficient to perform routine upkeep and servicing of assigned aircraft. NOTE: One of the main differences between the two types is the use of facilities provided by the FASRons.

A group of squadrons, comprising both fighter and attack, intended to operate as a unit aboard a carrier, is known as a Carrier Air Group (CVG). A group of patrol squadrons under one tactical commander is known as a Fleet Air Wing (FAIRWING).

Because his duties will be mostly maintenance of aviation fire control equipment, which includes guided missile external guidance and control, the Aviation Fire Control Technician will usually be part of the maintenance department within a squadron. Other departments in the usual squadron are: administration, operations, material, and gunnery (or ordnance).

The requirements for advancement in the Emergency Service Ratings and the Selective Emergency Service Rates programs are the same. Regular Navy personnel and Naval Reserve personnel striking for 3rd class petty officer must strike for either AQB3 or AQF3. Reserve personnel striking for 2nd class petty officer and above will continue in the Emergency Service Rating. Regular Navy personnel striking for 2nd class and above will continue in the General Service Rating. Refer to the study guide in the front of this course for a listing of the chapter that should be studied in preparing for your particular advancement.

FASRON.—A FASRon (Fleet Aircraft Service Squadron) is a shore-based commissioned unit designed to support a group of fleet squadrons. The FASRon acts as a coordinating agency between the shore facility and the fleet aircraft units in all logistic requirements except berthing and messing.

There are two basic types of FASRons, carrier and patrol. FASRons are designated as follows: 1–100, carrier type; and 101–199, patrol type. The departments of a FASRon are usually administration, operations, maintenance, supply, medical–dental.

The maintenance tasks assigned FASRons are SHOP MAINTENANCE and repair work required by aircraft assigned to the FASRon and the supported units. All shop maintenance performed in FASRon facilities by supported squadrons is under the coordination control of the FASRon.

AQ's attached to a FASRon are required to inspect, test, and repair all fire control equipment assigned to the FASRon or supported units. They will also be required to incorporate service changes as appropriate. Because the FASRon provides the facilities for maintenance, the technician must perform authorized repairs and adjustments to associated test equipment.

NAVAL AIR STATIONS.—Another possible billet for an Aviation Fire Control Technician is at a naval air station. Some air stations have an Overhaul and Repair Department. This department has aviation ordnance and armament repair sections where AQ's perform overhaul and major repair work on all types of aviation fire control equipment.

AIRCRAFT CARRIERS AND SEAPLANE TENDERS.—Aircraft carriers and seaplane tenders are organized into the following departments: operations, navigation, gunnery (or deck) engineering, supply, medical, dental, and air. The air department is divided into divisions, one of which is the aircraft maintenance division. Aboard the typical carrier or tender, the Aviation Fire Control Technician is part of the aircraft maintenance division. Generally the maintenance division afloat provides the same service to embarked squadrons as does the FASRon ashore.

TRAINING BILLETS.—In training billets, AQ petty officers serve as instructors in Naval Air Weapons Schools in which personnel are trained in the operation and maintenance of specific aviation fire control equipment. The instructors are carefully chosen from personnel experienced in aviation fire control. They conduct classes in many of the phases of fire control theory and practices, including such subjects as fundamentals of electricity and electronics, essentials of gyroscopes, computers, and servomechanisms. They instruct trainees in the authorized procedures for making operational and maintenance tests of the fire control equipment, and in the functions and operation of standard and specialized test equipment.

Test centers.—Aviation Fire Control Technicians are assigned to Naval Test Centers to assist in the work of testing and evaluating new aviation fire control equipment. Personnel of these test center units receive specialized instructions in the procedures for operating and servicing these control and guidance equipments. The development squadron to which development of the equipment may be assigned also assists in determining the suitability of new equipment for introduction into the fleet. These squadrons also work out procedures for training personnel in the use of the equipment and in rendering many other services to various naval activities in equipment test and development.

RESPONSIBILITIES AS A LEADER

There are certain things that every petty officer is supposed to know and be able to do. Whatever his technical specialty, he should know and understand general naval and military subjects. A petty officer should be able to take charge of a group of men. He is also expected to be able to show these men how the work should be done. He should know what to do, and do it, in matters of hygiene, first aid, fire prevention, damage control, and defense against the special weapons of modern warfare.

The responsibilities of a leader are twofold—to accomplish his mission, and to take care of his men. The general principles and techniques relating to the welfare and morale of the men are fully discussed in *General Training Course for Petty Officers*, NavPers 10055. These may be summarized as follows:

Know your men and look out for their welfare.

a. Learn as much as possible about their personal and family background without invading their personal privacy.

b. Be attentive to the health of your men; your close contact with them will permit you to detect evidence of ill health quite early.

c. Equalize the unpopular or dangerous details among your men.

d. Assist your superiors by reporting any conditions which obstruct your efforts to provide for the welfare of your men.

KEEP YOUR MEN INFORMED.

a. Pass on all information to your men which will help them in the performance of their duty.

b. Show your men how their efforts assist in accomplishing the mission of the larger unit.

c. Remember that you will be one of the first to hear false rumors; stop them before damage is done.

d. Seek information which is desired by and which will be useful to your men.

WORKING RELATIONSHIPS

Your working relationship with others is of utmost importance to the success of your work and the mission of your activities. While it is true that the mission of most naval aircraft is dependent upon the fire control equipment, there are many other factors that also contribute to the outcome of a flight. Don't let the difficulty of your work blind you to the importance of other rates. The only way to assure success is the traditional Navy spirit of teamwork and cooperation.

In your day-to-day working conditions you will be required to cooperate with others. The ability "to get along" is at times just as necessary as proficient technical skill. While it is the AQ's responsibility to boresight the gunsights, the ordnanceman is responsible for boresighting the guns. Needless to say, there has to be cooperation between the two. This spirit of teamwork will also be required in your working relationships with the electronic technicians, the electricians, and others.

The need for a harmonious working relationship also applies within your immediate rating. One of the main functions of a leader, and therefore a petty officer, is to instruct. As you climb the rating ladder, you will find that more men will look to you for instructions. You will also soon realize that one of the most vital factors in learning is the student's WILL TO LEARN. To develop this will to learn, thereby making the instructions effective, a smooth orderly working relationship is necessary.

SCOPE AND PURPOSE

The purpose of this course is to aid Aviation Fire Control Technician strikers to advance to Aviation Fire Control Technician 3. As is always the case, the use of this course must be accompanied by actual operation and maintenance of aviation fire control equipment.

This book was written with the assumption that before studying for advancement in rating the reader will have thoroughly acquainted himself with the basic NAVY TRAINING COURSES listed in the following section entitled "Knowledge and Skills Needed for Advancement."

Since men in the Aviation Fire Control Technician rating have a tendency to become experts on a group of systems or equipments, it is the present purpose to include more of the basic material which is applicable to all types of equipment rather than to emphasize a single system. When specific types are described in the text, this is done chiefly for the purpose of applying certain basic fundamentals or to the application of complex materials. Detail information on any particular piece of equipment will be found in the appropriate service manual or ordnance publication.

The scope of this course encompasses the subject matter and information, with exceptions, necessary for competent performance as an Aviation Fire Control Technician 3. As pointed out previously, the exceptions to this coverage are the subjects which have already been covered in the basic training courses.

In order to facilitate understanding of the purpose and function of the equipment, ballistics and the fire control problem are presented. This is followed by a discussion of the various types of equipments, such as sights, armament control systems, turret control systems, and bomb directors. Then come the chapters on maintenance, which essentially is the occupation of the technician. The final grouping of chapters comprises safety precautions and a discussion of the necessary clerical work.

KNOWLEDGE AND SKILLS NEEDED FOR ADVANCEMENT

The complete qualifications for advancement to Aviation Fire Control Technician are included in appendix VI. There you will find a listing of the knowledge and skills needed for advancement to AQ3. You will note a number of the qualifications deal with the principles of electricity and electronics. Because these subjects have been fully discussed in *Basic Electricity*, NavPers 10086, no attempt has been made to cover these particular qualifications within this course. The knowledge contained within *Basic Electricity*, with exception of chapter 15, therefore, forms a prerequisite to the study of the manual.

Before you study the courses on electricity you should become thoroughly acquainted with the following courses:

Mathematics, Vol. 1, NavPers 10069–A
Mathematics, Vol. 2, NavPers 10070–A
Basic Hand Tool Skills, NavPers 10085
Blueprint Reading and Sketching, NavPers 10077–A

Mathematics, Vol. 1, begins with a general statement of the basic principles of mathematics and presents a concise explanation of the use of whole numbers, fractions, decimals, and percentages. It gives a clear picture of directional angles, parallel lines, scale drawings, and triangles.

Mathematics, Vol. 2, continues with practical presentations of algebra, geometry, trigonometry, graphs, and logarithms. It concludes with an overall picture of measures of time and useful standard units.

Basic Hand Tool Skills presents, in a concise form, descriptions of the BASIC hand-tool operation. It contains information on layout, testing, checking, setting, and cutting. Although, for the most part, only hand tools are covered, a few illustrations of power equipment have been included.

Blueprint Reading and Sketching begins with a general discussion of the uses and kinds of blueprints. The text explains the language of a blueprint—lines, sections, symbols, dimensions, conventions, notes, and titles. Layout tools and geometry required, as well as procedures involved, are discussed. It concludes with sections on wiring and schematic diagrams.

But there is more to fire control than electricity and electronics, although they do play a major role. Optics, mechanics, hydraulics, and mathematics are subjects with which you will become familiar. A knowledge of the factors composing the fire control problem is also a MUST to the proper maintenance and adjustment of the equipment. You may rightly ask what is the use of knowing the theory of the fire control problem. It is true that you can handle many repair jobs just by memorizing a list of instructions or by using the practical experience obtained by helping other technicians.

Sometimes you will meet a problem that is not covered by instructions. If there is no one present to ask, you will be lost—unless you know the theory. Therefore, chapters 2 and 3 of this course are concerned with the factors composing the fire control problem.

Besides studying this course, you should become familiar with the publications on specific equipments. Among these publications are the *Handbooks of Operation and Service Instructions* prepared by BuAer.

SUGGESTIONS FOR STUDYING

As an aid in developing good study habits, first take a look at LEARNING itself. Learning has been described as the fulfillment of three conditions: The student must be convinced of the need, he must understand the lesson, and he must apply the acquired know-how. Notice that the emphasis is on the student. He has to get it himself—the instructor or book can only help. The instructor's duty is to assist him in learning as quickly and as thoroughly as possible.

To satisfy the first condition, you must have an interest in the rating. Apparently you have some interest since you are reading this course. Besides the obvious advantages of more pay and a step closer to the top, another reason for learning is the satisfaction of being able to do a job and to do it well. It follows then, in order to do a good job, you must have the necessary knowledge and skill. There are many other reasons that can be enumerated to show you a need for learning. But, whatever the reason, if you realize a sincere need for learning, the first condition has been met.

To help you meet the second condition, here are a few suggestions to help you in the study of this course. First read the chapter through fairly fast—as you would read a magazine article. If you encounter a difficult section, keep right on going. When you have finished the first reading of the chapter, answer as many questions as possible. Then go back and study the chapter very carefully, paying particular attention to the difficult sections. Once again answer the questions at the end of the chapter.

Occasionally you will find areas in which you will have to enlist the aid of your section leader and division officer for a proper understanding of the subject.

Ordinarily it is advisable to study the chapters in the order presented in the course. Occasionally you may find it necessary to look ahead or perhaps go back and restudy a chapter. Remember in the last analysis you are the person who has to understand it. Don't be half sure. Be certain of the subject after completing a chapter.

The third and final condition in the learning process is obtaining the know-how. Knowledge without the skill to apply it will avail you very little as an Aviation Fire Control Technician. It is an interesting commentary that, with other factors being equal, we remember approximately 10 percent of what we hear, 20 percent of what we read, 50 percent of what we see, and 90 percent of what we do. Therefore, in order to become a proficient Aviation Fire Control Technician, you will not only have to study hard but also work hard at your rate to develop the required skills.

The final suggestion is that you set a certain amount of time aside for studying each day. Remember to be reasonable in the time you set for yourself. Once you have designated a certain time for studying, stick to it and don't let anything stop you.

QUIZ

1. To permit effective delivery of an aircraft's weapons, aviation fire control equipment must assist the pilot or gunner to
   - a. position the weapons
   - b. position the aircraft
   - c. position the aircraft and weapons
   - d. continuously position the aircraft or weapons
2. The first type of aircraft gunsight was known as the
   - a. notch-and-post sight
   - b. telescopic sight
   - c. ring-and-bead sight
   - d. peep sight
3. In early aviation the fire control problem was
   - a. computed by a computer
   - b. computed by the pilot or gunner
   - c. completely ignored
   - d. estimated by the pilot or gunner
4. By the beginning of World War II ships were using fire control equipment; this equipment was not usable in aircraft due to
   - a. space and weight consideration
   - b. the constant advances that had been made in aircraft speeds
   - c. the fire control systems being unable to solve the air fire control problem
   - d. the short effective ranges of the aircraft's weapons
5. The lead-computing sight developed by the British during World War II was limited in range due to
   - a. optical focus and telescopic power
   - b. type of ranging and gravity drop
   - c. the short effective range of the aircraft's weapons
   - d. the limited range of radar
6. The lead-computing sight was improved to relieve the pilot of the task of manually ranging. Ranging was then done by
   - a. range estimations made by the pilot
   - b. automatic stadiametric ranging
   - c. infrared ranging
   - d. radar ranging

7. Dive, toss, and loft bombing techniques and equipment were developed for use against ________________ surface ships.
   a. maneuvering
   b. small
   c. fast
   d. large
8. Equipments used in an aircraft for effectively delivering its weapons is the responsibility of the
   a. Bureau of Ordnance only
   b. Bureau of Aeronautics only
   c. Bureau of Ordnance and the Bureau of Aeronautics
   d. Bureau of Aeronautics and the Bureau of Ships
9. The Bureau of Aeronautics has cognizance over all items of aircraft ________________, which includes fire control equipment, turret control system, and radars.
   a. electronics
   b. ordnance
   c. gunnery
   d. armament
10. Detailed information of the types of aircraft ordnance equipment is found in the *Bureau of* ________________ *Manual.*
   a. *Aeronautics*
   b. *Ships*
   c. *Ordnance*
   d. *Yards and Docks*
11. Armament control systems are identified by the ________________ designation.
   a. AFCS
   b. Mark and Mod
   c. Aero
   d. APG
12. Aircraft fire control systems are identified by the ________________ designation.
   a. ACS
   b. Mark and Mod
   c. Aero
   d. APG
13. What are the two general categories of the Aviation Fire Control Technician rating structure?
   a. Basic and supervisor technician
   b. Mechanic and supervisor technician
   c. Basic and mechanic technician
   d. Apprentice and mechanic technician

14. What are the three special groupings of the Aviation Fire Control Technician rate?
    a. Intercept, air-to-ground, and bombing systems technician
    b. Intercept, turret control, and bombing systems technician
    c. Air-to-air, air-to-ground, and turret control system technician
    d. Air-to-air, air-to-ground, and bombing systems technician
15. As defined by CNO, the daily preparation of aircraft for flight is called ________________ maintenance.
    a. line
    b. shop
    c. preflight
    d. hangar
16. As defined by CNO, the routine upkeep of aircraft is called ________________ maintenance.
    a. line
    b. shop
    c. preflight
    d. hangar
17. A group of squadrons, comprised of fighter and attack aircraft, intended to operate as a unit aboard a carrier is known as a
    a. Carrier Air Unit
    b. Carrier Air Group
    c. Fleet Air Wing
    d. Fleet Air Command
18. A group of patrol squadrons under one tactical command is known as a
    a. Carrier Air Unit
    b. Carrier Air Group
    c. Fleet Air Wing
    d. Fleet Air Command
19. What are the two types of FASRons?
    a. Carrier and land
    b. Land and detached
    c. Detached and patrol
    d. Carrier and patrol
20. The main difference between a self-supported and a supported squadron is that the supported squadron uses the facilities of a/an
    a. O&R (Overhaul and Repair)
    b. FASRon
    c. Fleet Air Wing
    d. self-supported squadron

21. Turret drives, pneumatic systems, and other turret equipment used as part of a complete fire control system are the responsibility of the
    a. AO
    b. AQ
    c. AE
    d. AD

22. How well the aviation fire control equipment does the job that it is designed to do is dependent upon the
    a. pilot
    b. factory
    c. AO
    d. AQ

23. Ordnance experts are of the opinion that during World War II superior ________________ enabled U.S. planes to win every combat in the air.
    a. firepower
    b. armament control systems
    c. fire control systems
    d. aircraft

24. The time the AQ sets aside each day for studying is done
    a. for advancement in rate
    b. to become a more efficient AQ
    c. to gain higher pay upon advancement
    d. to do all of the above

25. The AQ3 must not only be efficient in his technical specialty but he must also be
    a. a leader and be able to take charge of a group of men
    b. able to perform the jobs of rates associated with AQ
    c. able to perform instructor duty in Navy "A" or "B" schools
    d. a flight crewmember as well

CHAPTER 2

BALLISTICS AND TRAJECTORY FACTORS

BALLISTICS is a term which refers to the science of the motion of projectiles. It is a study of all the various forces, both controllable and uncontrollable, which govern the movements of projectiles. TRAJECTORY is the curve a projectile describes in space in passing from the muzzle to the first point of impact.

Previously, aviation fire control was defined as the applied science of continuously positioning an aircraft, its guns, or launchers to permit delivery of its weapons effectively against enemy targets. Knowledge of the motion of projectile as it travels toward the target is necessary to position the guns effectively. Therefore, the appropriateness of ballistics as a background subject to the study of aviation fire control can be appreciated.

The study of ballistics is normally divided into two branches. These branches are called INTERIOR and EXTERIOR ballistics. The study of interior ballistics is primarily concerned with the movement of projectiles inside the gun barrel, or bore. Exterior ballistics is concerned with the motion of the projectile after leaving the bore of the gun or the launcher. In the study of aviation fire control, exterior ballistics will be a prime concern. But, because the discussion cannot be complete without considering both parts, our first consideration will be the general aspects of interior ballistics.

INTERIOR BALLISTICS

Because there are a great many highly complicated technical subjects to be considered in the study of interior ballistics, detailed coverage of this branch will not be attempted in this course. However, in order to have at least an insight into the problems of interior ballistics, certain portions of the branch will be discussed here.

In the study of interior ballistics it is necessary to deal with the mechanical, ballistic, and service condition of the gun itself. The mechanical condition of a weapon has to be such that it will withstand the action of rapid combustion of the propelling charge. The weapon, or gun, itself must be designed to produce a given ballistic result in delivering a specified weight projectile at a given muzzle velocity with the minimum possible stress on the gun. Finally, the weapon must meet the service specifications with regard to ease of breech and loading operations.

Types and characteristics of powder charge or grain, ignition, and combustion, are all factors that have an influence upon the gas pressure. It is the gas pressure within the chamber that propels the projectile. Accordingly, there are two broad classifications of explosives: **HIGH EXPLOSIVES** as used in bombs and shells, and **PROGRESSIVE EXPLOSIVES** used in guns, rifles, and rockets. Our interest is in the progressive explosives, which are smokeless powder in one type grain or another.

It is interesting to note that smokeless powder does not detonate instantaneously but is "burned" in a measurable length of time. The time element is in the order of a fractional portion of a second resulting in appearance as an instantaneous detonation. The advantage of this burning is a comparative gradual evolution of gases; consequently, there will be much less shock and stress to the container.

Experiments have shown that the burning of smokeless powder takes place in parallel layers of the grain, and at a uniform rate or velocity. As each layer of molecules burns, the next layer is exposed to combustion. This process continues until the grain is consumed.

Because it is relatively difficult to ignite, an ignition charge is generally employed to ignite smokeless powder. A primer charge is used to set off the ignition charge.

Combustion of a grain of smokeless powder occurs entirely on its surface. Since this is true, the amount of surface on the grain determines the rate, or velocity, of burning. Various types and shapes of powder grains present varying amounts of surface to combustion. Therefore, by varying the amount of surface area per unit volume and varying the ingredients of the powder, great differences in speed of combustion may be obtained. The speed of combustion will affect the gas pressure, which in turn will affect the "initial velocity" of the projectile as it leaves the muzzle.

The potential energy of the powder used is another important aspect of internal ballistics. It is pertinent to observe that the potential energy of gunpowder is relatively low when compared with our common fuels, such as coal, oil, gasoline, and others. However, powder has such a tremendous RATE OF DELIVERY OF ENERGY that one would not consider offhand a comparison of explosives and fuels with regard to their "power" potential. The potential energy stored in a pound of smokeless powder (nitrocellulose) has been determined experimentally to be 560 foot-tons.

The powder, therefore, must be selected which will "fit the gun" under consideration. In the first place, the powder used must NOT burn so rapidly that complete combustion will occur before the projectile has started down the bore. If this were to happen, dangerous chamber pressures would build up causing probable violent rupture of the gun. On the other hand, the powder should have completely burned before the projectile actually leaves the muzzle of the gun in order that the total energy of the powder is utilized. Obviously, the Aviation Fire Control Technician will not make this selection of powder, but the knowledge gives him reason to insure that computer elements are correct and adjustments are made with a change in the type of ammunition used.

Temperature in the metal of the gun after firing is a factor in ballistics which has to be considered. As a result of the gun becoming heated during firing, there will be an increase in strength of propulsion and thereby an increase in the velocity of the projectile. Each gun has its own characteristics in this respect.

Heat cracks.—Heat cracks sometime develop within the bore of the gun during the service life of the gun. These cracks are caused by differential heating of the barrel from the surface of the bore toward the outside of the barrel, as well as the passage of the projectile through the bore. These cracks are generally not considered serious because their development is not critical within the extent of the accuracy life of the gun.

Erosion.—Erosion of the gun bore is caused by the intense heating of a thin layer of metal at the surface of the bore and by the rush of hot gases over this surface. Erosion results in a gradual enlargement of the bore and smooth wearing away of its surface. It begins at the rear of the bore and extends further down the bore as the gun is used. The lands are eroded about twice as fast as the grooves.

The service life of the gun is determined by the number of service rounds that may be fired through it before it loses its accuracy or sufficient energy to effect the desired trajectory. If erosion did not take place within the gun, the gun's service life would be spectacularly prolonged. A great many experiments have been performed in an attempt to lessen the rate of explosion. Cooler burning propellants, chrome plating of the bore, and projectile designs have individually and collectively reduced the erosion problem, but no way to eliminate it has been found.

There are naturally other factors which affect the overall service life of the gun. A few of these are improper cleaning, failure to clean, use of improper cleaning tools, exposure of gun to the elements, faulty preservation, incorrect lubrication for existing conditions, failure to replace worn parts when needed, failure to incorporate authorized changes to the gun promptly, and failure to maintain proper working clearances at all times.

EFFECTS ON TRAJECTORY

Exterior ballistics is the more important of the branches of ballistics with which the Aviation Fire Control Technician will be concerned. It is necessary for the AQ to have a practical knowledge of what happens to the projectile and the rocket after they are fired, before a reasonable understanding of the fire control problem may be obtained. The determination of the trajectory of a projectile of certain characteristics and given muzzle velocity forms the primary problem of exterior ballistics. As defined previously, TRAJECTORY is the curve a projectile describes in space in passing from the muzzle to the first point of impact. Our concern, then, will be with the factors which determine the trajectory in air-to-air and air-to-ground gunnery.

Gravity

GRAVITY is one of the factors affecting the projectile as it leaves the gun or launcher. It starts acting on the missile the instant it is free in the air. The gravity drop of a projectile in flight varies with the speed of the projectile and the total distance it travels. The distance that an object travels downward in a given period of time is a function of time. Therefore, the longer a projectile travels from gun to target, the longer will the gravity influence its path of flight.

Gravity drop is computed by the formula

$$s=\tfrac{1}{2}gt^2$$

where

s=the distance traveled

g=the acceleration of gravity (about 32 ft./sec./sec.)

t=the time of fall in seconds

This formula was developed for conditions in a vacuum, but is sufficiently accurate for computing trajectories of projectiles in still air.

Let us consider the case of a projectile leaving the muzzle of a gun and traveling 2,000 yards horizontally in 3 seconds. Ignoring all other factors but the effect of gravity, compute the distance that the missile would fall.

$$s=\tfrac{1}{2}gt^2$$
$$s=\tfrac{1}{2}\times 32\times 3\times 3$$
$$s=144 \text{ feet}$$

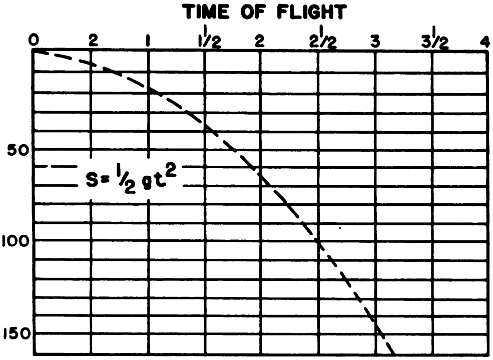


Figure 2–1.—Gravity drop of projectile.

Thus, the projectile would fall 144 feet in 3 seconds. This effect is illustrated in figure 2–1.

From the preceding it is apparent that in order to hit a target on the same level (altitude) as the gun, it will be necessary to elevate the gun. What would be the necessary elevation of the gun to hit the target? Before this question may be answered it is necessary to determine the means of measurement of elevation. The usual means used is the mil.

The mil.—The mil, being a unit of angular measurement, is defined as an angle subtended by an arc whose length is $\frac{1}{1000}$ of its radius—one inch of arc at 1,000 inches radius, one foot at 1,000 feet, etc. (See fig. 2–2.) In artillery and guided missile usage, a mil is equal to $\frac{1}{6400}$ of a circle. For most purposes these two values are considered equal. (The first being equal to 0.982 of the artillery mil.) Angular lead or deflection is usually computed in mils. A lateral lead of 10 mils for a target at a range of 1,000 feet would result in a difference of 10 feet between the sight line and bore line at

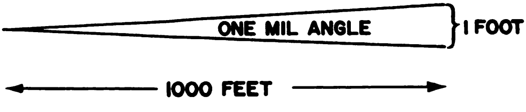


Figure 2–2.—Mil relation.

the target's range. The mil can also be used in the determination of range, and its use in this matter will be discussed later under "Gunsights."

You are now ready to answer the previous question: What is the necessary elevation of the gun to compensate for the effects of gravity while traveling 2,000 yards horizontally? A gravity drop of 1 foot at a distance of 1,000 feet in horizontal projectile travel is equal to one mil. Further, a drop of 6 feet at 6,000 feet (2,000 yards equal 6,000 feet) also equals one mil. Now, if the projectile drops 144 feet, then the angle of elevation necessary to compensate for this drop must be equal to 24 mils (144 divided by 6 equals 24).

Air Density

Air density is one of the factors which contribute to the resistance offered by the air to the flight of the projectile. Air density and velocity of the missile are the prime factors in the determination of the amount of resistance offered by the air. The effect of this resistance is the deceleration of the projectile and is more pronounced in the early part of the flight.

The cross sectional area of the projectile causes a friction to be developed between the projectile and the airmass. The amount of friction is dependent upon the density of the air and the size of the cross sectional area. It has been found that the denser the airmass the greater will be the friction offered to the projectile. Also, the larger the cross sectional area the greater will be the friction.

The end result of the friction offered the passage of the projectile by the airmass is a deceleration of the missile. The longer the distance of travel of the missile the greater will be the effect of air density, and therefore air resistance, upon the trajectory of the shell. The further the missile travels, the slower it will move. Eventually the projectile will be falling straight down.

In falling, the body travels faster and faster until the deceleration of the friction effect equals the acceleration due to gravity. Then the body continues toward the earth from the point in time at a constant rate of speed. Thus, a projectile fired horizontally from a high flying aircraft would start to drop after leaving the muzzle of the gun. Eventually the projectile would be falling straight down. Air density would be one of the factors that would determine the curve traced by the projectile in its transition from horizontal to vertical flight. The final velocity of the projectile in its downward flight would also be a function of air density. The importance of downward velocity can be appreciated when considering the time consumed in the drop of a bomb from any specified altitude. The time of drop is important in the determination of release point.

Among the factors that cause variations in the atmospheric density are variations due to changes in temperature and pressure, variations due to changes in altitude, and variations due to changes in moisture (relative humidity). The density of the atmosphere at a level above the earth's surface depends both upon the density at the surface and upon the altitude of the given level, since both temperature and pressure decrease with altitude. Because of fluctuations in air density caused by air currents or other influences at different heights, air density at any specific height cannot be expressed as a relationship between altitude and surface density. The only accurate means of determining air density at any certain altitude is the actual measurement of temperature and barometric pressure. Some airborne fire control equipment have the means for continuous measurement of both temperature and pressure.

While the relationship between density and altitude is complex, the relationship between density and its retarding effect upon a projectile is direct. It is commonly accepted that the retardation of a projectile varies directly in proportion to the density of the air. Therefore, regardless of cause, a given percentage variation in air density has measurable effect upon retardation of the missile. The amount of retardation of air resistance will help determine the time of flight of a given projectile for a specified distance.

Figure 2–3 shows three relationships between time of flight of a projectile and relative air density. A study of this graph will be worthwhile not only to show the relationship between the variable factors, but also to familiarize you with the use of this type of graphical representation.

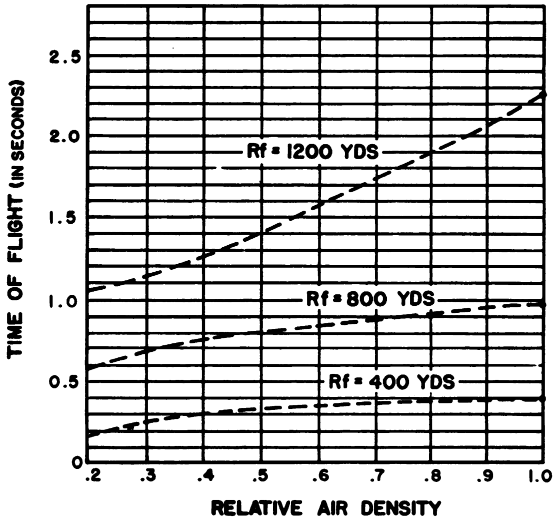


Figure 2–3.—Relationship between air density and time of flight.

Notice that there are three variable factors in figure 2–3. They are the time of flight along the vertical axis, the relative air density along the horizontal axis, and the future range (*Rf*). A change in future range is shown by a change in the actual curve used. All values along the 400-yard *Rf* (future range) curve are indications of time versus relative air density. In other words, when the range is 400 yards and the relative air density is 0.4, the time of flight will be 0.3 second. The curve also shows that when the range is 400 yards and the relative air density is 1, the time of flight will be 0.4 second.

If the range is 800 yards and the relative air density is 0.4, then the time of flight will be approximately 7.5 seconds. Increasing the future range to 1,200 yards (top curve on graph), an air density of 0.4 results in a time of flight of 12.5 seconds.

An examination of the curves shows that the difference in time of flight for the 400-yard future range is comparatively small across the whole scale of relative air density. At the same time the difference in time of flight for the 1,200-yard range with the change in air density is considerable. From this we can conclude that if the fire control equipment is to be used on short firing ranges, it may NOT be necessary to continually correct for the retardation effect of air density. It is pertinent to emphasize that the air resistance in itself does not need compensation. Compensation is necessary for the effect of gravity. The greater the air resistance, the longer the time of flight, and the longer the projectile's path is altered by the effects of gravity.

If the particular fire control equipment (whether fire control system or armanent control system) is to be used at various air densities and for controlling projectiles with comparatively long future range, the necessity for continuously measuring air density is apparent. As an Aviation Fire Control Technician, you should also be aware of the necessity of properly adjusting any controls in the air density circuits.

Muzzle Velocity

MUZZLE VELOCITY is the velocity of the projectile when it leaves the muzzle of the gun. The term INITIAL VELOCITY is often used in place of muzzle velocity. The muzzle velocity is important in the determination of the time of flight of the projectile.

The faster a body is moving through an airmass the greater will be the effect of air resistance and the greater will be the deceleration of the body. As the velocity of the body decreases, the deceleration effect becomes less. Therefore, the higher the muzzle velocity, the more the deceleration, and once again the greater the effect of gravity. (On the other hand, the higher the muzzle velocity, the shorter the time of flight and the resulting reduced time for the effects of gravity.) How these factors act and react will be discussed in chapter 3, "The Fire Control Problem." At the present time consider how muzzle velocity affects air resistance.

The effect of air resistance to the passage of a missile has not been overlooked by early investigators of this field. The great physicist and mathematician, Newton, seems to have been the first to deal quantitatively with this factor. He determined theoretically that the retarding of a missile due to air resistance must vary in proportion to the square of the velocity, PROVIDED diminishing pressure behind the missile and the airstream set up by friction were not considered. He tested his theory by dropping balls of various densities from the dome of St. Paul's Cathedral. He found that his theory held good for the rather low velocities he could obtain from this experiment.

However, time showed that the effects of air resistance on a missile could not be reckoned in such a simple quadratic law as Newton's. In 1742, Robins worked with his "ballistic pendulum" which absorbed the force of a missile in flight. He measured the resulting swing of the pendulum, and calculated the striking force from this measurement. This system proved to be accurate (or nearly so) up to velocities of 1,700 feet per second.

Later in 1840, Wheatstone suggested measuring velocities of missiles by using successive wire screen for the missile to cut in its flight path. These screens were placed in a circuit which incorporated a time measuring device. From these experiments with the screens and a special chronograph, a fairly accurate measurement of velocities was made in 1866–1870.

Wheatstone's work in the electrical timing and measuring initiated the first real progress in the science of ballistics. His principles have continued up to this date as essential factors in the advancement of this science.

From this we can conclude that muzzle velocity will influence the trajectory of a projectile. Although the greater the muzzle velocity the greater the air resistance, this is NOT a linear relationship. Further, if muzzle velocity influences the trajectory of the projectile, it must be taken into account in the solution of the fire control problem. Present day aviation fire control equipments do have the means for injecting the effects of muzzle velocity into the computation of the proper lead angle.

To complete the discussion of the subject, let us consider the factors which can change the initial velocity of a gun. These factors are changes in the projectiles and erosion of the gun barrel. Any radical variation in the powder, weight, or contour of the projectile will alter the muzzle velocity. The gradual enlargement of the bore, due to wear caused by firing, results in a gas escapement around the projectile causing a reduction of the initial velocity. Generally these considerations are refinements of the science, and usually the Aviation Fire Control Technician will set the muzzle velocity adjustments according to instructions from the Squadron Ordnance or Gunnery Officer.

Airspeed

A gun fired from a moving aircraft causes the projectile to move in the same direction and with the same speed as the aircraft carrying the gun. This increased momentum is, of course, in addition to the speed of the projectile itself. This is true provided that the gun is fired dead ahead, and the motion of both the projectile and aircraft are thought of with respect to a fixed point on the earth's surface.

In cases where the projectile is fired at an angle to the aircraft's line of flight, various values of the speed of the aircraft are additive, subtractive, or they cancel out in the determination of the total velocity of the projectile. It is easily understood that the projectile fired dead ahead will have a velocity (with respect to the ground) of the muzzle velocity of the gun PLUS the speed of the aircraft. For the projectile fired dead astern, the velocity of the projectile will be the muzzle velocity MINUS the speed of the aircraft. For projectiles fired at intermediate positions between dead ahead and dead astern, the velocity of the projectile will be the vector sum of the velocity of the aircraft and the muzzle velocity of the gun. At some angle back of directly abeam, the vector effect of the airplane's velocity will be canceled, leaving only the muzzle velocity of the gun. The resultant velocity will vary from the sum of the velocity at dead ahead to the difference at dead astern. This is shown in figure 2-4.

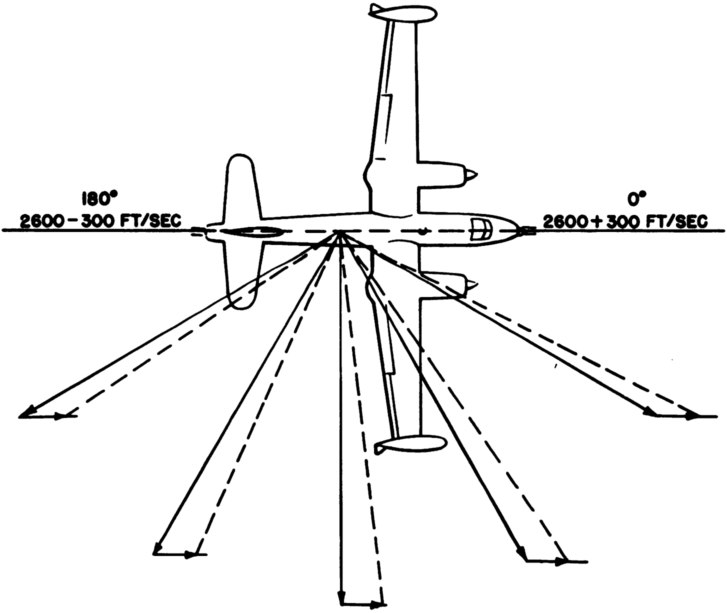


Figure 2-4.—Effect of aircraft motion on the projectile.

As the airspeed of the aircraft does affect the velocity of the projectile, it apparently must affect the trajectory of the missile. Airspeed affects trajectory because it is one of the factors that determines the time of flight of the projectile from gun to target. As before, the time of flight determines the time the projectile will be influenced by the force of gravity.

As Aviation Fire Control Technicians, it would be reasonable of you to expect a control or automatic device to compensate for the effect of airspeed on trajectory. Such is the situation. Fire control equipment for forward firing guns have both manual set controls and automatic systems for compensating for airspeed. By automatic is meant a system that, self-acting, will detect and note changes in aircraft airspeed. Sighting systems for use on guns movable throughout 360 degrees need devices to control the amount of airspeed compensation which is dependent upon the angle the guns are facing in respect to the direction of travel of the aircraft. Devices to meet such a need are used and are maintained by the AQ.

Temperature

TEMPERATURE, as such, usually is not a primary factor in consideration of gunnery trajectory. But because of the wide ranges of atmospheric pressure and temperature encountered by the aviation gun platform, unlike the surface platform, temperature is one of the factors to be considered in aerial gunnery. The density, pressure, and temperature at 30,000 feet is considerably different than surface conditions.

Effects from changes in temperature are usually secondary in nature, in that atmospheric temperature variations play a part in the determination of one or more of the primary factors of air-to-air trajectory. Because of these wide variations, some types of aviation fire control equipment do measure and use atmospheric temperature information in the solution of the trajectory.

As pointed out previously, air density will change with variations in temperature. One method used to measure air density is to measure both atmospheric temperature and pressure. When both of these factors are measured, they are combined in an electronic circuit which has air density as its output.

Temperature may be measured by several means. One method is to calibrate changes in a liquid pressure utilizing the principle that most liquids contract with a decrease, and expand with an increase, in temperature. Another method is to measure temperature changes by means of an electrical circuit with a resistor sensitive to air temperature. As the resistance of the resistor varies with temperature, it will result in a change in the amount of current in the circuit.

The amount of current can be used to actuate a recording or computing device.

Measurement of temperature also plays a part in the determination of true airspeed which is a necessary factor in air-to-air trajectory. Airspeed is measured by determining the difference between pitot pressure and static or barometric pressure. Pitot pressure is received from the pitot tube and is the impact pressure of the airstream as the airplane moves through the atmosphere. This pitot pressure is compared with static pressure to determine airspeed. Because temperature will affect air density and air density affects pressure received from the pitot tube, free air temperature must be applied to correct airspeed to true airspeed. True airspeed is the factor of direct importance in establishing the trajectory of airborne projectiles.

Effective rocket temperature.—The trajectory of a rocket is affected by the temperature of the propellant grain. It is therefore necessary to know the approximate temperature of the propellant in order to determine the correct sight setting. When the rockets are held at a constant temperature for a considerable length of time before firing, this temperature may be considered the temperature of the propellant. When the external temperature is changing, different parts of the propellant will be at different temperatures. The term "effective rocket temperature" of such a round refers to that average temperature which, when used in the sight setting, will give the proper answer.

The importance of ascertaining the approximate temperature of the rocket propellant can be realized by a study of figure 2–5, which indicates the errors introduced by a misestimate in temperature.

If a pilot in a 40-degree dive at 300 knots, firing from a specified launcher at a 1,500-yard range, has computed his sight setting on the assumption that the temperature is 70° F. when in reality it is 60° F., he will make an error of only 1 mil. Recall that a 1-mil angle with a 1,500-yard range results in an arc of 1.5 yards. Considering the ammunition dispersion, such an error may easily be tolerated. On the

(REPRESENTATIVE ROCKET)

SLANT RANGE YDS	0°F	40°	70°	100°	0°	40°	70°	100°
	HORIZONTAL FLIGHT 200 KNOTS				HORIZONTAL FLIGHT 300 KNOTS			
500	3	2	1.5	1	2	1.5	1	0.5
1500	4.5	3	2	1.5	2.5	2	1	0.5
	40° DIVE 200 KNOTS				40° DIVE 300 KNOTS			
500	2.5	1.5	1	0.5	1	1	0.5	0
1500	2.5	2	1.5	0.5	1.5	1	1	0

Figure 2–5.—Error in mils caused by 10° F. error in estimate of temperature.

other hand, at low temperatures, low speeds, and small dive angle, the errors become considerably larger.

From the preceding discussion, it can be seen that the effective rocket temperature is important in sighting. Aviation fire control equipment used for calculating the correct sighting for rockets incorporate means for determining and compensating for changes in rocket propellant temperatures. These means are both the automatic type and the manually set control. As AQ's, your interest in these devices not only lies in the understanding of the equipment but also in following the correct preflight adjustments and procedures.

Recently, rockets have been developed which have temperature-insensitive propellants. When these rockets are placed in service, the necessity for measurement of effective rocket temperature will have ended.

Rotation of Projectile

All guns are rifled the length of the bore in order to impart a spinning motion or rotation to the projectile. (See fig. 2–6.) This spinning stabilizes the projectile in flight. The grooves and lands of the rifling are so constructed as to give a clockwise rotation to the projectile, as viewed from the rear of the gun. Since a rotational motion is imparted to the projectile during its progress down the bore, the pro-

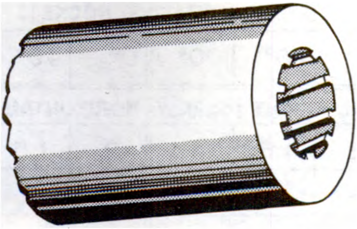


Figure 2–6.—Aircraft gun's rifled bore.

jectile in free flight becomes a gyroscope. It attempts to obey all the laws of the gyroscope.

A projectile during flight is subjected to a force which causes it to DRIFT. Drift is the sideward curving of the point of fall from the original plane of fire. (See fig. 2–7.) This deviation is due entirely to the effects set up by the rotation of the projectile. There are other lateral deviations such as wind that have an effect on some projectiles. However, they should not be confused with pure drift. While there is no complete agreement as to some of the details, generally there are three accepted causes of drift in an elongated projectile. They are: (1) gyroscopic action of the rotating projectile, (2) action of the air adhering to the projectile, and (3) the cushioning effect of air banking on one side of the projectile. The latter two causes are generally thought to have only very minor effects as compared to the first.

The gyroscopic action of the projectile while spinning in flight tends to keep the projectile's axis in the direction of the line of departure from the gun. However, the center of gravity of the projectile in flight tends to follow the curved path of the trajectory. The instantaneous direction of its motion at any point is that of the tangent to the trajectory. Air resistance opposes the flight of the projectile and works against its underside with greater force than elsewhere as shown in figure 2–7.

An overturning or tumbling motion results as the center of gravity and an extension of the center of pressure to the axis of the projectile become further separated. However, the gyroscopic force of the projectile opposes this upsetting

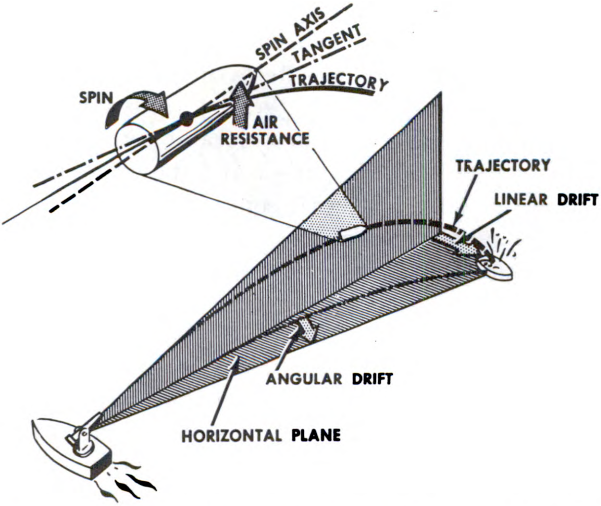


Figure 2–7.—Drift of a projectile caused by gyroscopic action.

or overturning moment, and tends to keep the axis in the original direction. This gyroscopic moment which opposes the upsetting moment, in accordance with the laws of the gyroscope, causes a precession of the projectile about the direction of the force as it tries to overcome the tendency of the projectile to overturn. Also, according to the laws of the gyroscope, the precessional revolution of a projectile having a right-hand spin, must be clockwise when viewed from the rear.

Wind

Some of the preceding effects upon trajectory are reserved for consideration of projectiles propelled from guns. Among these effects are the muzzle velocity and the rotation of the projectile. Others of the previously discussed effects have their influence on all types of projectiles. Gravity and air resistance will effect not only gun-propelled projectiles and rockets but also bombs. But, wind fits into an entirely different category, in that it must be considered in the air-to-ground problem but not in the air-to-air problem. WIND is defined as the motion of the air relative to the earth.

AIR-TO-AIR TRAJECTORY.—Because of the relatively short distances involved and the short time of flight of projectiles in the air-to-air problem, the effects of wind are not a factor in the determination of the trajectory. This may be visualized by considering the wind as a block of air, a frame of reference, containing both the target and the gun. If both the target aircraft and the aircraft containing the gun or rocket launcher are in this mass of air, they will be affected equally and in the same direction when considered in respect to the ground.

If considered only in respect to each other and the mass of air, there will be no change in their relationship caused by the movement of the airmass. As an analogy, consider a fly in a closed, moving automobile. The movement of the automobile does not affect the relationship of the fly and any object in the interior of the automobile. In the same manner, any missile propelled from an aircraft toward another airborne target will be unaffected by the movement of the airmass through which the missile is moving. This lack of effect will NOT be true for projectiles launched from surface platforms or from airborne platforms and directed against surface targets.

AIR-TO-GROUND TRAJECTORY.—In bombing ground targets from an aircraft the bomb is released without any propelling force. As it travels through the air, the forces of gravity and air resistance will act upon it. The initial velocity of the bomb is the true airspeed of the aircraft. The trajectory of the bomb will then be determined by the effects of gravity and air resistance. If a wind is blowing, it will also act upon the bomb and will cause it to drift with respect to the ground. This drift may become a serious factor in bombing.

In order that the effects of wind on a bomb trajectory will have more meaning for you, a brief discussion of some of the aspects of the bombing problem will be presented here. A more complete discussion of the bombing problem is included in a later chapter of this course.

To facilitate the understanding of a bomb's trajectory, consider an imaginary situation—the release of a bomb in a vacuum from an aircraft. The motion of the bomb imparted by the moving aircraft, plus the time of fall, determines the range. Range is the total horizontal distance the bomb moves forward from the place of release until impact. In this theoretical case, there will be only two forces acting on the bomb. These are gravity and the motion of the aircraft. The bomb will be directly beneath the aircraft at the time of impact.

Since it is necessary to consider air resistance in order to deal realistically with the problem of trajectory, it is necessary to cover the problem of trajectory in air. There will then be four forces acting on the bomb. These forces are the force of gravity, the air resistance in a vertical direction which opposes the pull or force of gravity, the motion imparted to the bomb by the aircraft, and the air resistance in the horizontal direction which opposes the forward motion of the bomb. The air resistance in the vertical direction causes the bomb to decrease in velocity at any instant during its fall, and thereby increases its TIME OF FALL. The longer the time of fall, the longer the bomb will be subject to the force of the wind. Air resistance in the horizontal direction causes the bomb to trail behind the vertical of the aircraft. In other words, when the bomb reaches the point of impact, it will NOT be directly beneath the aircraft.

With a constant airspeed and course, the horizontal distance that the bomb has lagged behind the airplane at the instant of impact is called TRAIL. The amount of trail is governed by the aircraft's airspeed at the time of release, and the length of time the air resistance acts on the bomb. The amount of air resistance is determined by the air density (hence, the altitude) and the bomb's physical characteristics (shape, weight, and size). It is important to note that these three factors which determine trail—airspeed, altitude, and bomb characteristics—are unaffected by the presence of wind. Therefore, trail is independent of wind and has the same value in a headwind or a tailwind that it has in still air. Trail and range are shown in figure 2–8.

The principal effect of winds along the line of the heading of the plane, that is, either headwinds or tailwinds, is the change made in the closing speed of the aircraft. Assuming

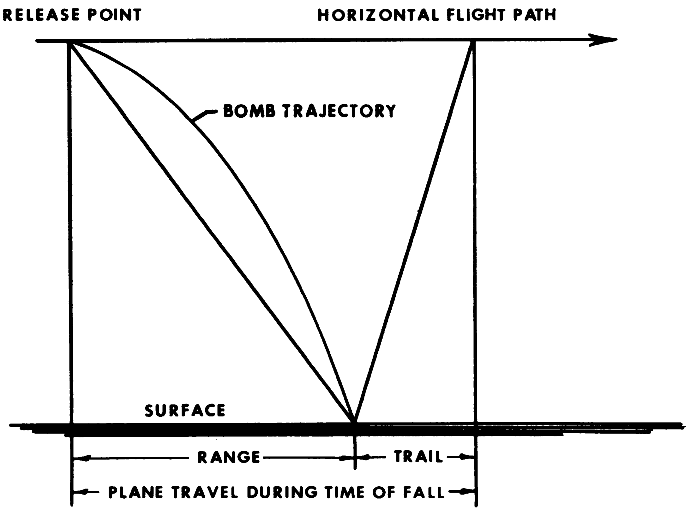


Figure 2–8.—Horizontal bombing.

that the target is stationary, if there is no wind, the closing speed is equal to the true airspeed of the plane. In a headwind, the closing speed equals true airspeed minus wind velocity. In a tailwind, closing speed equals true airspeed plus wind velocity. The trail value remainds unaffected and is the same for all three cases. The reason for this is apparent when it is realized that the closing speed of the bomb is the same as that of the aircraft at the moment of release.

When the aircraft is headed either directly into the wind or downwind, its course over the ground is the true course flown. In other words, it makes its own course good over the ground. In all other instances the course steered will not be the actual course over the ground. Therefore, there will be an angle formed between the course the aircraft is steering and the course it makes good over the ground. This angle is called the ANGLE OF DRIFT and is shown as the angle between the airplane heading and airplane path in figure 2–9.

Associated with the angle of drift is another factor called CROSS TRAIL. (See fig. 2–9.) Cross trail is the distance the

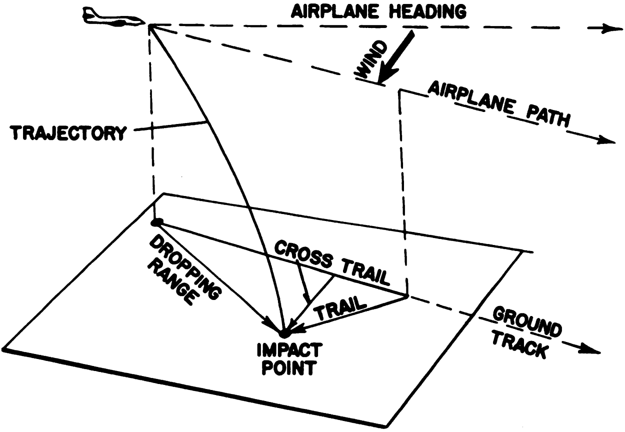


Figure 2–9.—Effects of cross wind on bomb trajectory.

bomb falls toward the downwind side of the target due to the combination of drift angle and the natural trail of the bomb. To compensate for cross trail, it is necessary for the aircraft to fly a course which takes it to the upwind side of the target a predetermined amount, or distance which corresponds with the amount of cross trail existing.

Rockets.—Wind will also affect the trajectory of a rocket fired at a SURFACE TARGET. The rocket's time of flight for a given range determines, in part, the extent to which the trajectory will be affected by wind. As with other projectiles, the time of flight will be determined by the velocity, the range, and the air resistance.

The influence of wind on an aircraft at the firing altitude causes it to drift. This motion is retained by the rocket when it is fired. The magnitude of drift for a rocket with a given time of flight varies with (1) direction of the wind relative to the aircraft's heading, (2) wind force, and (3) angle of dive.

In computing the aiming allowances for wind, it is assumed that the air moves as a body with the same speed and direction at all altitudes. The effect of wind can be visualized by considering the air as a stationary mass and the earth as moving with the velocity of the wind. Thus it is obvious that the wind will cause the hitting point on the earth to move a distance equal to the product of the time of flight and wind velocity. This also serves to illustrate that the aiming allowances for wind and target motion are the same magnitude.

Because wind does affect the trajectory of the rocket in its course from aircraft to target, aiming allowance must be used to compensate for the effect. A cross wind deflects a rocket the full amount of wind velocity multipled by the rocket's time of flight, regardless of dive angle. Compensation for a cross wind then requires full wind aiming allowance.

An oblique wind is defined as one from such a direction that its apparent path in the sight is midway between the horizontal and vertical cross lines. An oblique wind exerts only part of its force in changing the course of the rocket. The shallower the dive, the less the rocket is affected and the less aiming allowance required. The steeper the dive, the greater the effect and aiming allowance approaches that for a cross wind.

Angle of Departure

As mentioned previously, the trajectory is the curve a projectile describes in space in passing from the muzzle to the first point of impact. The ORIGIN of a trajectory is the position of the center of gravity of the projectile at the instant it is released. The tangent to the trajectory at its origin is the LINE OF DEPARTURE. (See fig. 2–10.) The angle that the line of departure makes with the horizontal is the initial angle of inclination of the trajectory and is also called the ANGLE OF DEPARTURE.

Consider once again the imaginary situation of a projectile fired in a vacuum. The trajectory is shown in figure 2–10. The projectile will have two motions. One is the motion along the line of departure at a speed equal to the initial velocity, and the other is the effects of gravity—a falling motion straight down at a constantly accelerating speed. At the instant the projectile leaves the gun, it will be falling.

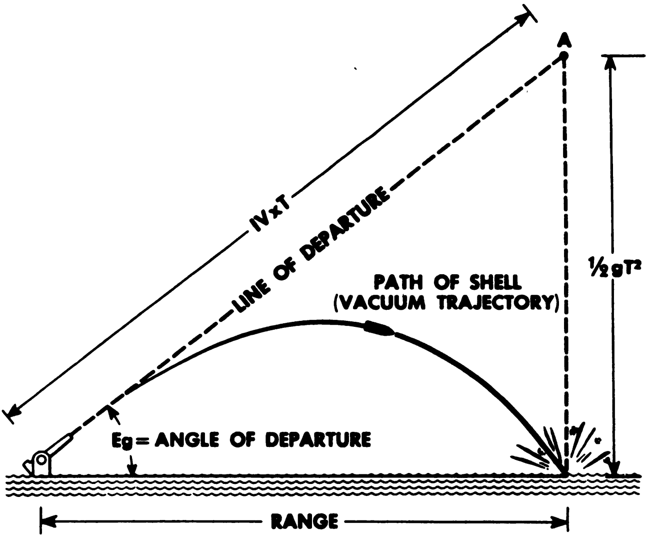


Figure 2–10.—Path of projectile (vacuum trajectory).

It falls slowly at first, so most of its motion will be upward and forward along the line of departure. As it travels farther, it will fall faster, until the falling speed equals the upward speed along the line of departure. This is the highest point or the middle of the missile's path. As it continues to fall, gravity will be pulling it down faster than momentum (always constant in a vacuum) is carrying it up. Its path will curve downward more and more steeply, until it finally hits the surface.

The distance from the gun to the point where the projectile hits the surface is the range of the gun at that particular elevation. The range will change at different elevation angles. When the tilt of the line of departure is moved upward, the projectile's initial velocity tends to carry it higher. Thus, the projectile will have farther to fall before it hits the ground. The reason is that it takes longer for the missile to fall to earth, and during this longer time it has a chance to go farther forward.

A headwind or tailwind at shallow angles acts only to retard or accelerate the rocket by a negligible amount; requires little, if any, aiming alowance. As the angle steepens, headwind or tailwind exerts more and more force in changing the course of the rocket and the aiming allowance approaches that for cross wind.

The aiming allowance for wind is always applied upwind and that for target motion is applied in the direction of the target motion. Tables giving the aiming allowances have been tabulated for each general type of ammunition.

In the present lead-computing sights, the effects of wind are treated as target motion. These systems will compensate for windage or target motion as long as the pilot maneuvers the aircraft so as to keep the pip on target. It is essential, in accurately aiming rockets, that the tracking be done smoothly from the time the approach is initiated until the rockets are released. This smooth tracking is necessary for the equipment to determine the correct point of aim. Because the angle of dive has a definite influence on the effects of wind and therefore the trajectory, means are incorporated to compensate for different angles of dive.

Self-Propelling Force of Rockets

The problem of how to aim and fire rockets from aircraft is considerably more complicated than that of aiming and firing bullets. The complications stem mainly from the ballistics of the rocket and the method of launching airborne rockets. The two are not easily separated since the trajectory of the rocket depends upon the manner in which it is launched as well as other considerations. One of the main influences upon the trajectory of rockets is the fact that it is self-propelling.

As stated previously, a bullet is hurled forward by the pressure of gases expanding in the firing chamber. It has top speed when it leaves the muzzle. A rocket, which is propelled by jet force of gases produced by burning the propellant charge it carries, starts rather slowly. Because a rocket starts slowly, has a long flight time, and tends to turn downward due to fin and the jet effects, it has a very curved trajectory.

Unlike a gun, even the largest rocket exerts no recoil on its launcher. The back pressure is absorbed in the open air. The only purpose of the launcher is to hold the rocket in place and point it in a given direction, until fired. Because of the "no recoil" feature, an aircraft can fire as large or as many rockets as it can carry. A fighter plane's salvo of 5-inch High Velocity Aircraft Rockets (HVAR) is the equivalent of a destroyer's salvo power.

It is instructive to note the differences, related to the methods of propulsion, in the trajectory of rockets and machinegun bullets. These differences are: (1) the velocities, (2) the direction of flight, and (3) the trajectory curvature.

Rockets are slower. The velocity of the fastest rocket used at present in forward firing is considerably less than that of a machinegun bullet. Furthermore, it takes the rocket a relatively long time to reach its maximum velocity, whereas the bullet has its maximum velocity as it leaves the muzzle. The consequent longer time of flight of the rocket to a given range means that allowances for target speed and wind are much greater than in the case of machinegun fire.

Rockets tend to follow the direction of flight of the aircraft, while bullets travel in the direction of aim. The bullet travels close to its direction of aim because the muzzle velocity is so much greater than the speed of the airplane that the effect of the latter upon the motion of the projectile is slight. The fins of a rocket, on the other hand, tend to aline the projectile with the airflow. Since the launching speed is small compared to the speed of the aircraft, the rocket is quickly alined with the resultant airflow—that is, almost completely in the direction of the line of flight of the aircraft. This deflection toward the flight path is greater the less the launching speed of the rocket, and is almost 100 percent with zero-length launchers.

The rocket trajectory is characterized by considerable curvature compared to the flat trajectory of a bullet. Not only does the longer time of flight lead to a greater gravity drop but, in addition, as the rocket falls, the fins tend to aline it along the trajectory, so that there is also a component of the jet force downward, contributing to the normal gravity drop. The consequent large curvature means that the sighting allowance required in aiming, and its variation with dive angle, are much greater for rockets than for guns.

As the angle *Eg* in figure 2–10 is increased and the gun is elevated, the projectile is given more upward movement. Of course, it is also given less forward movement. If this angle is increased above 45 degrees, the time the projectile is traveling will continue to increase, but the forward movement will be so much slower that, even in the longer time, the missle will not go as far. Obviously, if the gun is directed straight up from a stationary platform, the range will be zero. Maximum range is obtained (in a vacuum) at an elevation at 45 degrees. Some typical trajectories are shown in figure 2–11. Notice how the range varies with the different elevation angles.

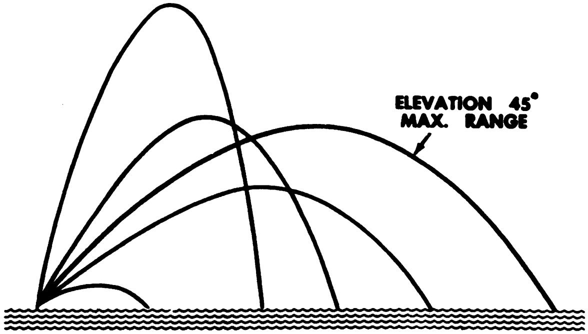


Figure 2–11.—Trajectories in a vacuum.

As you would expect, the trajectory of a projectile will be considerably altered by its travel through air. A comparison of the air trajectory and vacuum trajectory is shown in figure 2–12. Air alters the shape of the trajectory in several different ways. The striking velocity of the projectile no longer equals its initial velocity. The angle of departure no longer equals the angle of fall. Range is greatly decreased. Also, as pointed out previously, the projectile acts like a gyroscope. All these factors must be considered in

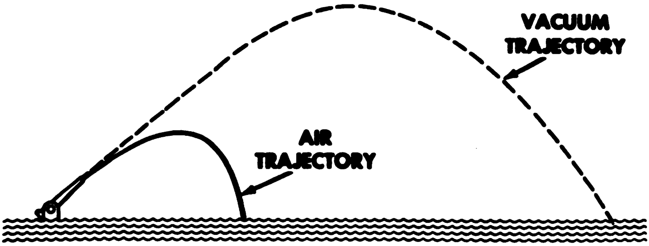


Figure 2–12.—Vacuum and air trajectories.

aiming the guns. Some of the latest equipment go to great length to measure and compensate for each factor. Other types of equipment compensate for some factors but not all of them.

As an example, one particular type of aviation fire control system utilizes an accelerometer to measure the *g*'s pull on the projectile at the time of release. The symbol for the force of gravity is *g*. If the angle of departure varies, the effect of pull of gravity on the projectile will vary. Actually the force of gravity is the same regardless of the angle of departure, but the effects of gravity will change with the angle of departure. The reason for this, as given under the discussion of trajectory in a vacuum, is that the trajectory is the result of two motions—the forward motion and the downward motion. If the forward motion is reduced, then the trajectory will be more influenced by the downward motion—gravity. Thus, the accelerometer measures the *g*'s pull on the projectile and modifies the gravity lead computation to compensate for this *g*'s pull.

The angle of departure is also important in determining the flight path of rockets. The angle of the launcher in respect to the aircraft armament datum line will determine the angle of departure of the rocket from the aircraft. The armament datum line is the longitudinal reference line fixed relative to the aircraft by boresight fittings provided for that purpose. In some control systems, means are provided to compensate for any angular difference in the launcher line and armament datum line.

UNIVERSITY OF ILLINOIS
LIBRARY

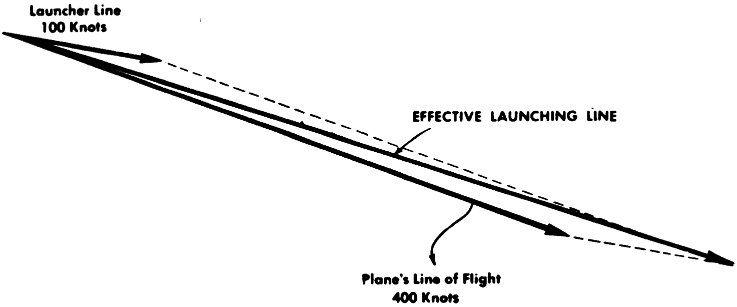


Figure 2–13.—The effective launching line.

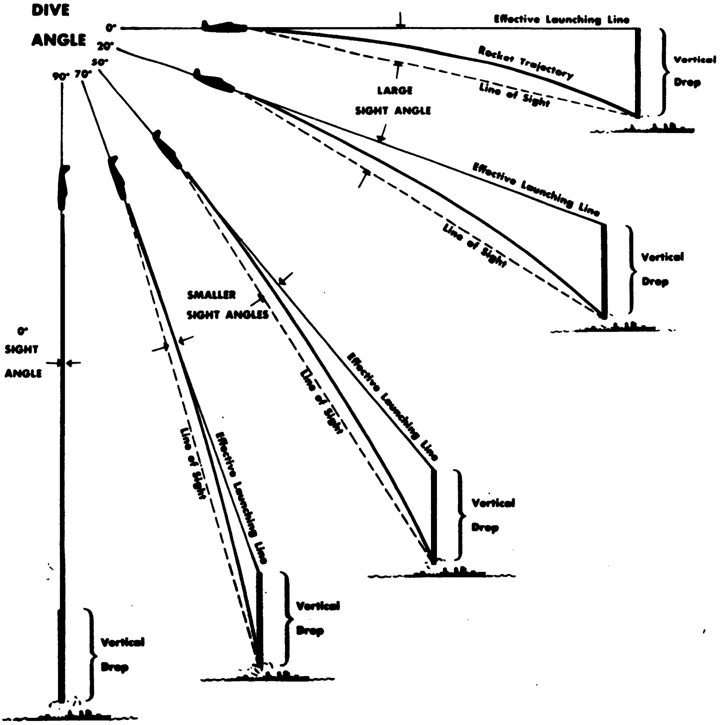


Figure 2–14.—Effect of angle of dive.

The rocket's actual line of departure is a compromise between directional forces. One is the rocket's own motion, weak at first, along the launcher line. The other is the plane's motion along its line of flight, a strong force also imparted to the rocket. The actual direction taken by the rocket is the resultant vector of these two forces, known as the EFFECTIVE LAUNCHING LINE. (See fig. 2–13.)

The plane's attitude along the line of flight, its angle of attack, is particularly significant in aiming rockets. It influences the position of the effective lauching line and the angle between the zero line of sight and the effective launching line. The three types of attitudes are: (1) zero angle of attack, (2) nose up or positive angle of attack, and (3) nose down or negative angle of attack.

The effective angle of departure of a rocket is also going to be influenced by the effect of the angle of dive. The steeper the dive, the less the vertical pull of gravity affects the rocket's trajectory and the smaller the aiming allowance for vertical drop. When the effective launching line points straight down, the force of gravity simply adds to the impetus of the rocket along this line. As the effective launching line moves toward the horizontal, the more gravity deflects the rocket from its initial path, and the larger the sight angle required. (See fig. 2–14.)

METHODS OF OBTAINING BALLISTIC INFORMATION

Our major concern up to now has been the explanation of the effects of certain factors on trajectory. These factors form a portion of the consideration in determining the proper lead angles for aiming projectiles from a moving aircraft. The remaining considerations are concerned with the relative motion between gun and target. These will be discussed in the next chapter on the fire control problem. To conclude our discussion on ballistics, let us examine the method of obtaining and incorporating ballistic information.

Although most of the factors affecting the trajectory of the projectile may be approximated by mathematics, it is generally more accurate to determine the effect of each factor experimentally. Each new type of gun is fired exhaustively at the test grounds and a set of tables is drawn up from these firings. This set of tables shows the effect of each factor on the trajectory of the missile. In order to determine what the projectile will do when fired, all that is required is that the set of tables be read using the ballistics information acquired with various measuring devices. This information obtained experimentally is called EMPIRICAL INFORMATION. The various systems have means for inserting this necessary information in the computation of the correct lead. As you advance in your studies, you will see that these tables may be read electronically in a ballistics computer.

As an example, consider the Aircraft Fire Control System Mk 16 which is an automatic lead-computing pilot-operated system designed for aiming the aircraft in the fire control of fixed, forward firing guns and rockets. One of the advantages provided by this system is that it is not limited to any one type of armament. The system will accurately compute the point of aim for any service type of gun and rocket in either air-to-air or air-to-ground combat. The ballistic constants required by the computer circuits of the system for the ammunition to be used are preset before flight by inserting suitable plug-in ballistic elements. There is a separate plug-in-unit for each type of gun and for each type of rocket.

As Aviation Fire Control Technicians, you are not required to determine the factors incorporated by the plug-in units. But, an appreciation of how various ballistic factors do influence the trajectory of the projectile, should make you aware of the necessity of being certain that the correct plug-in unit is used for the type of ammunition or rocket in service. Further, the need for exacting care in making adjustments and in maintenance should be apparent.

PRESENTATION OF EMPIRICAL INFORMATION BY GRAPHS

You have already used graphs representing empirical information. Examples of these graphs are figure 2–1, gravity drop of a projectile, and figure 2–3, relationship between air density and time of flight. In the graphing of empirical information, first a set of tables is made containing the necessary data. From this table of data, the information is transferred to graphs.

As an example of this construction of a graph, consider figure 2–1. In this graph we have plotted the drop of a projectile caused by gravity against the time of flight. To do this, the first requirement is tabulation of the necessary data.

Time of flight	0	½	1	1½	2	2½	3	3½	4
Distance drop	0	4	16	36	64	100	144	196	256

Each point is then located on the graph and a smooth line joins all of the points together. To determine the distance traveled for 1.6 seconds, it is necessary to draw a line vertically from 1.6 to a point that intersects the curve. From the point of intersection a line is drawn horizontally to the left-hand index. The distance traveled is read as approximately 42 feet.

Any set of conditions may be graphed in this manner as long as there is one dependent and one independent variable. In other words, variations in one factor result in variation in another. In the preceding example, the amount of drop of the projectile is dependent upon the elapsed time.

Ballistic data are published for each rocket type. These data consist of tables of trajectory drops, launching factor, flight times, projectile velocities, and other factors bearing upon the rocket's trajectory. These data are obtained by repeated firings of rockets both on the ground and airborne. Because the characteristics of the aircraft will also affect the trajectory, these tables are constructed for particular rockets to be used in specified aircraft. The main objective of these field ballistic tests is to determine sight settings for a particular aircraft which is firing rockets. These sight settings are determined under a limited number of sets of conditions and are then used in the construction of the sighting tables. Photography is used to obtain a continuous record of the instrument readings during the trial runs.

QUIZ

1. In connection with the general subject of ballistics, which of the following explosives is an example of a PROGRESSIVE EXPLOSIVE?
   a. Grenade
   b. Rocket
   c. Bomb
   d. Shell
2. In considering the combustion of a typical smokeless powder, how would the BURNING RATE most likely be INCREASED?
   a. By increasing the size or bulk of each grain
   b. By increasing the amount of primer material
   c. By decreasing the surface area of each grain
   d. By increasing the surface area of each grain
3. The service life of a typical gun would be affected MOST by
   a. exposure of gun to the elements
   b. improper cleaning
   c. heat cracks
   d. erosion of bore
4. What could be considered the primary problem in the scope of exterior ballistics?
   a. Determination of projectile trajectory
   b. Amount of gravity drop
   c. Velocity of burning of the propellant
   d. Computation of range to target
5. **Consider a projectile fired horizontally from a platform and neglecting air resistance. How far would it fall if it travels 3,500 yards in 3.33 seconds?**
   a. 52.8 feet
   b. 177 feet
   c. 105.6 feet
   d. 352 feet
6. A lateral lead of 8 mils for a target at a range of 2,000 yards would result in a difference between the sight line and bore line, at the target's range, of
   a. 16 yards
   b. 72 feet
   c. 48 yards
   d. 96 feet

7. What would be the necessary elevation for a gun to compensate for gravity (neglect all other factors) while a projectile travels 3,000 yards in 4 seconds?
   a. 28.44 mils
   b. 85.3 mils
   c. 48 mils
   d. 56.88 mils
8. Resistance to the flight of a projectile is offered by air. Which factor below tends to decrease this resistive effect?
   a. Denser air
   b. Higher muzzle velocity
   c. Minimum weight of projectile
   d. Reduction in cross-sectional area
9. Many factors cause variations in atmospheric density. Which of the items below is one of these factors?
   a. Airspeed
   b. Temperature
   c. Pitot pressure
   d. Initial velocity
10. Which one of the following items would be a major factor in CHANGING the initial (muzzle) velocity of a projectile?
   a. Elevation angle
   b. Air density
   c. Erosion of bore
   d. Relative humidity
11. In the determination of true airspeed, which of the following items is most necessary?
   a. Time of day
   b. Pitot pressure
   c. Relative humidity
   d. Temperature
12. Which of the factors below must be considered for the air-to-ground, bombing, and ground-to-air problems but not for the air-to-air problem?
   a. Range
   b. Air density
   c. Time of flight
   d. Wind drift

13. Consider an imaginary bombing problem—the release of a bomb in a vacuum from a moving aircraft. If all factors at the time of release are considered constants, where will the bomb be relative to the aircraft at impact?
    a. Directly beneath the aircraft
    b. In a direct line but behind the aircraft
    c. In a direct line but ahead of the aircraft
    d. Directly below the point of release

14. There are four forces that primarily affect the fall of a bomb in air—force of gravity, air resistance in a vertical direction, motion of bomb imparted by the aircraft, and air resistance in the forward direction. Which of these can produce the greatest variation in time of fall?
    a. Gravity
    b. Motion of bomb imparted by the aircraft
    c. Air resistance in the vertical direction
    d. Air resistance in the forward direction

15. The amount of ________________ for a bomb dropped from an aircraft is governed by the aircraft's speed at the release time, and the length of time the air resistance acts on the bomb.
    a. fall time
    b. drag
    c. trail
    d. range

16. The closing speed of an aircraft during horizontal bombing in a headwind is equal to
    a. true airspeed minus wind velocity
    b. wind velocity minus true airspeed
    c. indicated airspeed plus wind velocity
    d. true airspeed plus wind velocity

17. The deviation between the course the aircraft is steering and the course the aircraft makes over the ground is called
    a. trail
    b. angle of drift
    c. corrected heading
    d. flight line

18. The influence of wind on an aircraft causes it to drift. This motion is retained by the rocket when it is fired. The magnitude of drift for a rocket for a given time of flight varies with the
    a. angle of dive
    b. type of rocket
    c. altitude
    d. angle of skid

19. The distance a bomb falls toward the downwind side of a target as a result of the combined action of drift and natural trail of the bomb is called
    a. cross drag
    b. trail
    c. ground track
    d. cross trail

20. Which of the following statements best defines the action of a cross wind acting on a rocket?
    a. It deflects the rocket proportionate to dive angle.
    b. Deflection equals full wind velocity times the rocket velocity.
    c. Deflection equals full wind velocity times the rocket's time of flight.
    d. It deflects the rocket at an oblique angle with shallow dives.

21. Consider the trajectory of a projectile in a vacuum. The highest point or middle of its path is defined as the point where its
    a. terminal speed is zero
    b. speed of fall equals its upward speed along the line of departure
    c. gravity begins to affect the trajectory of the projectile
    d. angle of departure is maximum

22. When firing a projectile in a vacuum, the maximum forward (horizontal) range is obtained with a gun elevation of ________________ degrees.
    a. 22.5
    b. 30
    c. 45
    d. 50

23. In firing rockets from an aircraft the actual line of departure is governed by several factors. The effective launcher line is the
    a. plane's attitude along the flight line minus the angle of attack
    b. vector resultant of the aircraft's flight line and launcher line
    c. angle difference between the zero line of sight and the angle of attack
    d. difference between the boresight datum line and the angle of skid

24. In ballistics and associated studies, tables of EMPIRICAL INFORMATION are often found. This is information that is
    a. generated by computing machines
    b. derived from factual laws of physics applicable to the subject
    c. tabulated from experimental data
    d. computed prior to the designing of the gun

25. A simple graph in the study of ballistics would be the one covering the drop of a projectile as a function of time. In the gravity formula that equates drop distance and time, which of the following statements is true?
   a. s is the dependent variable.
   b. g is an independent variable.
   c. t is the dependent variable.
   d. s is the independent variable.

CHAPTER 3

THE FIRE CONTROL PROBLEM

THE FUNDAMENTAL PROBLEM

The fundamental fire control problem is to determine the correct direction to aim the armament in order to insure a hit when the target is within range. To do this, it is necessary to find the target and properly identify it by ascertaining that the intended target is NOT friendly. There are four main phases of the problem: Acquisition, identification, ranging, and tracking.

Acquisition Phase

As the name implies, the acquisition phase is the initial contact with the target. This contact may be made by visual means or by some aided means, such as radar. The limitations of visually detecting a small aerial target at considerable range are apparent. Among the factors which contribute to the limitations of visual means are:

1. The difficulty of detecting a small spot within the large aerial volume in front of an aircraft.
2. The difficulties imposed by adverse weather.
3. The difficulties imposed by night operations.
4. The physical strain upon pilot and/or crew of continuous examination of large areas of air and surface.
5. The already complicated task of flying high-speed, high-performance aircraft.

Because of these limitations on visual means, the most common means of acquisition of a target by airborne fire control equipment is radar.

Radar is a special radio system which projects ultrahigh-frequency pulses and determines the PRESENCE and POSITION of unseen objects by reflected echoes, that is, a means of radio detection and ranging.

Radar is composed of a directive antenna system, a transmitter-receiver combination, an indicator, and several other devices to control and supply power to the basic elements. Radar has a direct application to aviation fire control. It gives the operator, whether pilot or crew, accurate target information even though the target may be hidden by darkness or fog, and also supplies information which may be used for the determination of the correct lead for hitting the target. To determine a target's position, the distance or range to the target, its elevation relative to the gun platform, and its relative bearing must be known. Radar gives all three of these spatial coordinates.

The initial contact then, with the target, is usually made by the search radar. Search radars are designed to keep a large aerial volume, either surrounding or in front of the aircraft, under nearly continuous observation. The outstanding advantage of search radar over optical search is their freedom from restrictions regarding visibility and lighting. Radar, too, has disadvantages. The most serious being the probability of interception by an enemy detection unit. Because radar energy drops off as the square of the distance, radar signals can be detected at least four times as far as a radar can detect targets.

But the high speed of present day targets requires that search be carried out to a long range. The necessity of keeping a large region under continuous surveillance imposes a limitation on the accuracy of target position information. The search radar examines the searched region by the rotation or oscillation of a directional antenna, which successively illuminates all portions of the search region. When operated and interpreted skillfully, the search radar can give a surprising amount of information.

Besides the possibility of using the radar within the aircraft for detecting the targets, systems have been developed where the interceptor is "vectored" to the approaching enemy or unknown aerial target by means of a surface radar. Some of the day interceptors use relatively simple optical fire control systems, while some of the all-weather interceptors have amazing complex electronic fire control equipment. The purpose in both cases is to complete the solution of the fire control problem. In this situation, the first phase, acquistion, is supplied by the surface detection units.

Identification Phase

Once a target has been selected for investigation, the second phase of the airborne fire control problem is the IDENTIFICATION of the target. The problem of recognizing and identifying a friend or foe is as old as warfare. Passwords, flag hoist signals, and distinctive uniforms are identification devices that have been used for thousands of years.

In modern warfare the identification problem has a new urgency. Radar systems present targets in the form of spots on a screen, but both friendly and enemy planes appear as spots. Further, high-speed planes and guided projectiles leave little time for resolution of doubts. In the past, friendly fighters pursuing enemy planes within machine-gun range of our ships were confused with enemy planes and were fired upon. Also, enemy planes have followed our fighters returning to their mother ship and have discovered our carriers' location. Proper identification can prevent such confusion.

Security is another phase of the identification problem. If the enemy were able to use the identification system, he could make deadly approaches before being identified properly. The security problem is aggravated by the fact that identification devices must be available not only to the numerous units of our forces but also to those of Allied Forces. In an attempt to prevent airborne units of identification systems from falling into enemy hands, destructors and firing circuits that can be operated by the pilot, or that operate on impact, are provided.

IFF (identification, friend or foe) determines whether the target is a friend or enemy. Electronic methods of identification have many of the same advantages over optical methods that radar search has over optical search. As with other equipment, the IFF system will not function if the equipment fails or if the operator neglects to turn on the transpondor according to plan. A transpondor is an electronic device which automatically transmits an identifying reply when it receives an interrogation pulse.

Identification is initially conducted in conjunction with search. The search radar challenges the target by activating the IFF interrogator. This equipment sends out pulses to trigger the transpondor carried by friendly planes. If the target is friendly and is emitting proper recognition signals from its transpondor unit, a coded pattern appears on the identification indicator screen at the search radar. If the target is unfriendly and is not returning proper signals from a transpondor unit, no pattern appears on the screen. The IFF transmitter is synchronized with the associated radar equipment so that a "challenge" pulse from the transmitter is fed to the identification antenna and is sent out at the same time that a pulse is transmitted by the radar equipment. This serves to place the identification reply signal at the same spot as the radar echo signal. One weakness of IFF systems is the difficulty of associating the reply signal with the indication of the target from which it comes. This difficulty is inevitable with the uninterrupted sweep of the antenna of search radar.

Ranging Phase

Once the target has been acquired and identified, the third phase, RANGING, becomes the active portion of the solution of the fundamental problem. Ranging is of utmost importance in determining the aim necessary to obtain a hit. Knowledge of the range of a target is also necessary because of the limited effective range of guns, rockets, and missles. As in the other phases, there are two basic means for determining range. They are visual and aided means.

STADIAMETRIC RANGING.—The most common method of visual or optical ranging employed in aircraft fire control equipment is stadiametric ranging. Stadiametric ranging is the determination of the distance to an object by means of triangulation . It is based upon the same principles as the stadimeter used today aboard ship to determine the distance or range of another ship or object. It is an interesting commentary that this system of ranging has been used both by the sailing shipmaster in the graceful clipper ships of the past and the jet pilot in the sleek interceptors of today.

The shipmaster estimated the distance to shore or to another ship by holding his thumb vertical at arm's length. He then compared the known height of the ship's mast or the lighthouse to the height of his thumb. In this method of estimation there were three known lengths—the lighthouse, the thumb, and the arm. The unknown element was the distance from the master to the lighthouse. He determined this distance by comparison and experience.

Figure 3–1 shows the method of determining range by triangulation or similar triangles. The factors known in the problem are the length of AB, CB, and ED. The length to be determined is the length of line AD. It can be shown that the corresponding sides of similar triangles are proportional. Similar triangles have corresponding angles equal, such as triangles ABC and ADE shown in figure 3–1. Therefore, the following relationship is true:

$$\frac{CB}{ED}=\frac{AB}{AD}$$

Substituting numerical values and simplifying, results in

$$4AD=36$$

or

$$AD=9$$

Therefore, the distance from A to D is 9 feet.

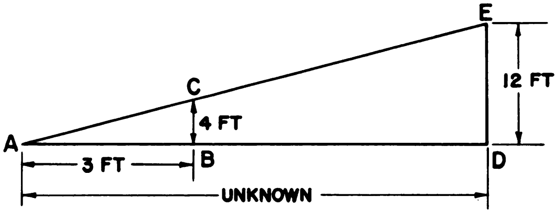


Figure 3–1.—Distance determination by similar triangles.

Before continuing with the discussion of present day ranging, the term reticle and reticle image should be explained. Webster defines a RETICLE as a system of lines or wires in the focus of the eyepiece of an optical instrument. The reticle used in gunsights and aviation fire control equipment usually consists of opaque disks containing geometrical openings. Behind the reticle or disks is a source of light. Thus, the light coming through the opening forms a pattern called the RETICLE IMAGE PATTERN. By adjusting the distance between the reticle openings, it is possible to control the diameter of an imaginary circle formed by the reticle image.

In the lead-computing sights used in present day interceptors, range is stadiametrically measured by recognizing the target wingspan, setting that in the sight, and then spanning the target by adjusting the reticle diameter. There are several methods in use for adjusting the reticle diameter. Thus, if the target is continuously framed by the reticle image, the diameter of the reticle will vary as the range varies. In this manner not only can the range be determined, but the rate of change of range can also be measured. The rate of change of range is an important function in the solution of the fire control problem.

As shown in figure 3–2, when the target is framed by the inner points of diamond-shaped pips, the following geometric relationship exists:

$$\frac{R}{f}=\frac{S}{d}$$

where

R=target range
S=the wingspan of the target
f=distance from pilot's eye to reticle image
d=diameter of the reticle image pattern

By knowing the wingspan, the distance to the reticle image, and the diameter of the reticle, it is a simple matter to determine the range of the target.

From figure 3–2 it can be seen that f and S are constant. As the target approaches and the range decreases from R to R_1, it is necessary, in order to frame the target, to increase the diameter of the ranging reticle image from d to d_1 by adjusting the reticle. Thus, range is measured stadiametrically, and the rate of change of range can be determined.

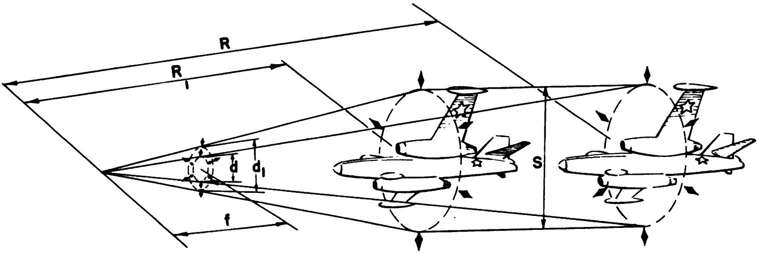


Figure 3–2.—Geometric relationships of stadiametric ranging.

RADAR RANGING.—Radar ranging is by far the most common method of ranging in use today. Basically, radar presents information to the operator concerning the presence and position of unseen objects by reflected echoes. A brief description of how radar accomplishes this mission is presented here in order that you will have insight into this means of determining the range or distance to a target. A more complete introduction to radar is contained in *Basic Electronics*, NavPers 10087.

The operation of radar is dependent upon the generation in the transmitter of very powerful pulses of radiofrequency energy. These pulses are then sent out from the directive antenna in the shape of a beam and they travel at the speed of light. When the beam strikes an object, a small portion of the energy is reflected back and picked up by the antenna in the form of an echo. The echo is then amplified in the receiver and shown as a "pip" on a cathode-ray oscilloscope. The directivity of the antenna provides a means of determining the direction of the target. Pulse transmission is usually used and enough time must elapse between successive pulses to allow for the reception of the echoes without interference.

Measurement of distance is possible because radio waves travel in a straight line at a constant velocity of 162,000 nautical miles per second. The principle of measuring target distance is relatively simple. Each distance is computed from a measured value of time. A pulse of **RF** (radiofrequency) energy leaves the radar antenna and travels to a target. Part of the energy is reflected by the target and returns to the antenna as an echo which is picked up and sent to the receiver. The amount of time required for the sequence of events depends on the distance to the target and back. The distance to the target thus can be computed as half the product of rate of propagation and the elapsed time. Notice that the distance is equal to half the product; the entire product would result in the distance from the radar to target and back. Effectively, then, the time for the energy to reach the target measures the distance or range.

Tracking Phase

The fourth and final phase of the fundamental problem is TRACKING. Tracking is very often done in conjunction with ranging of the target. Once the target is within range, it must be tracked to obtain the fire control information necessary to accurately aim the projectiles. As in the previous phases of the problem, there are two major means of tracking to be considered: (1) by an optical system, and (2) by radar. Incidently, fire control systems are also classified as belonging either to the director system or the disturbed system. Normally, the optical type is a disturbed reticle system and the radar type is a director system.

OPTICAL SYSTEM.—This system depends on the pilot's or gunner's tracking ability for target position and rate information. In the optical system, the gunner or pilot keeps the target framed within the ranging circle formed by the reticle image. The operator must be able to see the target and must aim by means of the optical sight. In the interceptor, the pilot must fly the fighter so as to superimpose the gyro reticle image of the sight over the target. The motion of sight supplies target direction and rate information. This information, which is fed to a computer by the system, is then indicated to the operator by means of a reflector-type sight unit.

It is essential that the tracking be smooth if the computer is to determine the correct lead angle. To hold the reticle image on the point of aim for the target may even necessitate a change in the angle of attack of the aircraft. The resulting course described by the interceptor aircraft in air as it tracks a target is called a PURSUIT COURSE.

In like manner the gunner must move his turret smoothly, whether occupied or remote controlled, keeping the gyro reticle image on the point of aim of the target. As in the pilot-operated sight, the point of aim is computed by the system and is indicated to the gunner by means of a reflector-type sight unit. Once again smooth operation is necessary for the computer to calculate the correct lead angle.

RADAR.—There are several different systems in use at the present time that depend upon radar for tracking. They differ mainly in the amount of automation in the manner in which tracking information is relayed to the pilot or gunner. The two major methods for relaying this information from the radar are: (1) by means of a cathode-ray tube, and (2) by means of an optical sight system.

The FIRST method to be considered is an automatic system of radar tracking. During search operation the radar echoes are displayed on a cathode ray tube with the gunner responsible for the selection of a target. In this system once the target has been selected by the operator, the equipment "locks-on" the target. The radar then automatically follows the target keeping the guns positioned continuously at the proper attitude to hit the target.

Because the guns are automatically positioned, this system is usually employed in the defense of a bomber or attack aircraft. But it is very possible that the system could be used to control a fighter or interceptor. For our purpose, we will consider the system as controlling a turret.

After the system is in track operation, the radar scanner and the turret do not respond to the movements of the gunner's control handles. The radar scanner automatically follows the angular movement of the target. Also, the turret is positioned to the proper lead angle for the projectiles to hit the target when it is within range.

By the scanner following the target, the necessary azimuth and elevation tracking information is obtained and fed to the computer. The computer, after determining the correct azimuth and elevation displacement, positions the guns accordingly.

Means are also included to terminate automatic tracking by depressing a switch. The system will then return to search operation. The tracking in this system is completely automatic only requiring the operator to select the target and fire the guns at the proper time.

The SECOND radar method also uses radar for tracking and the cathode ray tube for displaying the information, but DOES NOT automatically position the guns. This method is used by fighter aircraft. During air intercept (AI) search operation, the radar maintains a constant surveillance over the space in front of the aircraft with target echoes displayed on the scope (cathode-ray tube). By means of a manual control on the radar, the pilot may select for automatic tracking any target appearing on the scope.

This selection of a target for automatic tracking is accomplished by positioning a small diameter circular trace known as a TARGET STROBE. The pilot positions the strobe by a position lever on the radar until it encircles the target. However, the antenna continues its regular search scanning until the pilot operates a lock-on control. This control initiates automatic tracking of the target in range, azimuth, and elevation. The antenna then ceases its regular scan and is driven until it coincides with the target's azimuth and elevation positions.

During automatic tracking, the presentation on the scope differs greatly from that during search. The entire presentation including the target strobe is replaced by a target dot. The target dot indicates the course that the pilot must fly in order to overtake the target and commence offensive action. A ballistics and flight data computer supplies the computed lead angles to the scope in the form of voltages which deflect the target dot. Displacement of the target dot from the intersection of reference cross hairs indicates to the pilot the direction that he must maneuver his aircraft in order to establish the correct lead angles so that projectiles from the aircraft's guns will strike the target. Note that the target dot is not actually the target echo but the point of aim computed from ballistic and flight information.

In this system the pilot selects the target and then flies the aircraft through a lead pursuit curve. The lead pursuit curve is determined by ballistics information, both preset and acquired, plus the flight information. The pilot is free during tracking to concentrate on flying the aircraft.

The THIRD method to be considered is the type in which the radar is used for tracking, but the tracking information is used to control an optical sight in place of displaying it on a scope. The radar system is an automatic range measuring device which produces the range information in the form of a voltage proportional to the range.

This radar set searches out a preselected maximum range. The radar stops searching when it locates a target and remains locked on the target until released by a switch. The radar also informs the pilot when lock-on occurs and the system is tracking.

The actual tracking for azimuth and elevation is accomplished by means of an optical fire control system. The range tracking information, determined by the radar, is inserted into the optical system thereby freeing the pilot from manipulating any controls to obtain this range tracking information.

In this system, the pilot flies a pursuit course as determined by the optical fire control equipment using the radar for ranging. Because it utilizes an optical system, this method cannot be classified as an all-weather system. The following advantages of this system are: It is less complex, weighs less, and is not as dependent upon electronic equipment as the previously mentioned systems. The advantage in not being dependent upon electronic equipment is that electronic equipment is subject to inflight failure.

The FOURTH system may be classified as a combination system. It is similar to the second system in that it uses a radarscope for selection of the target. The pilot directs the radar beam in the direction of the target. Upon release of an action switch, automatic tracking display appears on the radar screen.

This display provides the pilot with the following information: The direction in which to steer the aircraft towards the target; the speed at which the target is, or is not, being overtaken; and a very accurate indication of target range. The steering information is provided by a steering reference circle and a steering dot. The position of the steering reference circle with respect to the center of the indicator screen indicates the position of the tracked target relative to the heading of the aircraft. The steering dot functions as a vernier for the steering circle resulting in greater accuracy.

The pilot flies the scope by maneuvering so as to first center the stering circle on the scope and then center the steering dot within the steering circle. When the steering dot is centered, the target is dead ahead and the aircraft is flying toward the target on a pursuit course.

This system is like the third system in that it utilizes an optical fire control system (disturbed reticle) for computing the correct lead. The radar does not contain the lead-angle computing feature.

When the target becomes directly visible, the pilot completes the attack by the use of the optical sight, which places a sighting pattern of light on the glass windshield. He then steers the aircraft to keep this pattern in line with the target.

The FIFTH system to be considered is also a combination system but not in the same sense as the previous system. Recall that one method of acquisition was by "vectoring" an interceptor by means of a surface radar. This radar tracking system under consideration depends upon surface direction and visual acquisition. The radar is used for tracking the target and guiding a self-propelled missile.

The acquisition is accomplished when the fighter director officer on the carrier vectors the pilot to intercept the target. The pilot places his radar in the mode of operation which causes the antenna to be pointed dead ahead. With the radar in this operation, the pilot searches for the target which must be acquired optically. The radar range circuits search automatically for the target, and the range search sweep is shown as a panel indicator.

As soon as the pilot sights the target, he maneuvers for a tail or head-on attack, centering the target in the optical reticle so that the radar can acquire it. When the range is closed to within a prescribed range, the radar locks-on, at which time an indicating lamp is energized, and the range indicator stops sweeping and indicates the range to the target.

The pilot then switches to the tracking mode of radar operation. In this mode of operation the radar set tracks the target automatically within a narrow angle and provides a missile guidance beam that is essentially independent of aircraft motion. The radar set computes an area of optimum launching range on the basis of the closing speed of the aircraft. When the range to the target becomes optimum, a warning signal circuit is energized and remains energized so long as the range lies within the optimum area.

While the range warning signal circuit is energized and the aircraft is in approximately straight and level flight, the pilot launches a missile by pressing the firing button. At the end of a short period of free flight, the missile is well ahead of the aircraft in the radar beam, and the period of guided flight begins. The missile maneuvers to fly at the center of the beam. As the radar beam moves to follow the target, the missile adjusts its flight path to remain in the center of the beam. This results in an intercept or collision course with the target.

PURSUIT AND COLLISION CURVES

The problem of determining pursuit curves has a long historical background. The military aspects of the problem were brought into prominence in connection with aerial combat wherein one aircraft is attacked by another possessing guns capable of being fired in a fixed direction only. In order for the one aircraft to keep the other under continuous fire, it must fly some kind of a pursuit course. The problem appears again with the invention of homing missiles which continuously change heading under radio, optical, or acoustic guidance unwillingly supplied by the target.

The importance of pursuit courses in air-to-air combat is twofold. The attacker (fighter) flying an aircraft equipped with fixed guns must understand such a course in order to determine whether or not his aircraft can fly the required flight path. The defender (bomber) uses his knowledge of the flight path to determine the future positions of the attacker. This establishes the required leads for his guns.

In general, a fixed weapon fighter flies one of two courses when attacking a target. These are the PURSUIT COURSE and the COLLISION COURSE. A pursuit course (fig. 3–3) is flown when the firing aircraft maneuvers in such a manner as to be in a position to fire upon the target continuously throughout the run. In order to produce hits, the fighter is constantly pointing ahead of the target by the correct lead angle, and a projectile fired at any time (within range) can be expected to score a hit. In the process of tracking the target, the pilot must fly a curved path, the curvature de-

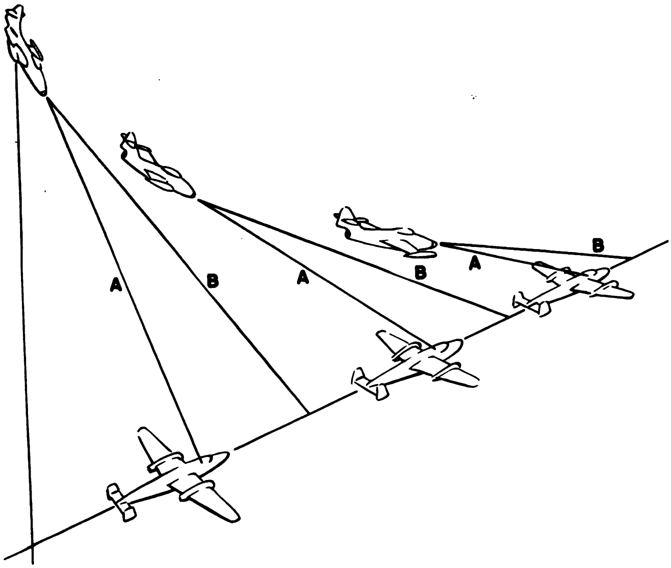


Figure 3–3.—Typical pursuit course.

pending upon the range, relative target speed, and angle of approach to the target.

On this course the weapons are within range of the target and are bearing on it for several seconds; consequently, many rounds of ammunition may be fired. Therefore, the pursuit course is used when employing multiple projectiles, such as in machinegun fire.

If this pursuit course is carried through, the fighter will eventually be in a tail chase, and the target, if a bomber, can concentrate defensive firepower in its tail, making the last stage of a pursuit course very dangerous.

The collision course (fig. 3–4) is a straight-line course in space (assuming target velocity to be constant) that positions the fighter so that its projectiles, fired at one point on such a line, will score a hit. There is only one point on such a line where firing will be effective. Therefore, the collision course is used when a single salvo of projectiles, such as rockets or guided missiles, is employed. These usually discharge a large amount of ammunition almost instantaneously, thereby increasing the prospects of a kill.

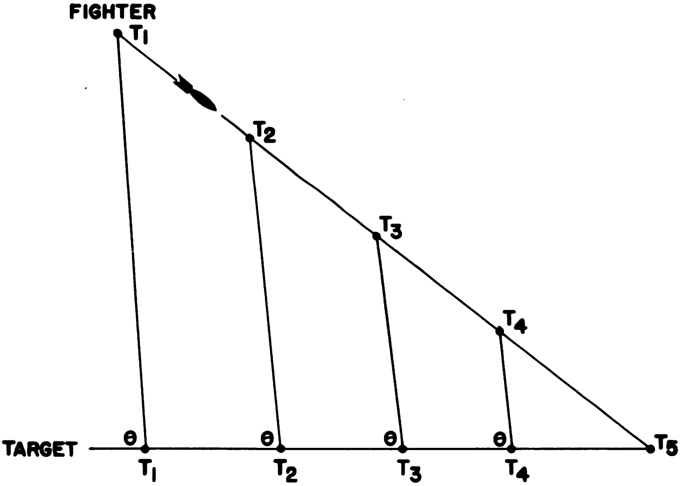


Figure 3–4.—Collision course.

The pursuing aircraft flies on a prescribed course at a prescribed speed. These are determined by the computers after the target is tracked. At the proper time (T_1), the missile is automatically released. The missile flies in a collision course with the target, bearing a constant angle from the target at all instants of time (T_2, T_3, T_4). Finally, at time T_5, it strikes the target, assuming that the missile maintains a constant velocity.

The chief advantage of the collision course is that the fighter flies a straight-line flight path. This enables the fighter to reach the firing point faster and break away from the area of defensive fire sooner and with less maneuvering. Note that the moment of firing from a lead collision course, the fighter is at one position of a pursuit course and could transfer to a pursuit course.

Before continuing our examination of the airborne fire control problem, let us consider the ideas of velocity and acceleration. A firm understanding of these subjects is mandatory to the understanding of the fire control problem.

A casual observation of the physical world reveals some bodies, such as buildings, to be at rest; while others, such as automobiles, are in motion. Further investigation shows that these objects previously considered to be at rest are really in motion because they are moving with the earth. Also, the movement of the earth is relative to the sun; and the sun is in motion in respect to some so-called fixed point. From this we can conclude that apparently all things are in motion, and the physical condition of being at rest means to be moving at the same rate as some other object. The science that treats the motions considered in themselves is called KINEMATICS. (Kinematics is a widely used term in the literature of fire control.)

Of course our concern is not directly with the science itself but rather with some of the ideas developed in the science. One of the elements in the solution of the fire control problem is the effect of the relative motion between the aircraft and its target. Two of the main considerations in determining the effect of this relative motion are the CHANGE

IN DISTANCE and the CHANGE IN ANGLE. This section is concerned with an examination of the rate of change in distance (range) or linear velocity and acceleration. Angular velocity and acceleration, which deals with the change in angle, will be discussed in the next section.

While the idea of range is generally well known, the concept of rate of change of range does not enjoy such familiarity. As a method of analysis, let us first define the words. RATE is the amount or degree measured in proportion to something (in this case—TIME), while RANGE, of course, is the distance between the aircraft and its target. A combination of these two definitions must result in range rate being the change in distance as measured in proportion to time.

LINEAR VELOCITY.—Although often freely interchanged, the words speed and velocity do NOT have the same meaning. Speed is a reference to the distance covered in a unit of time and is a scalar quantity. Velocity involves both speed and direction, and is a vector quantity. Velocity, then, is the time rate of change of position.

If an aircraft is flying east at 300 miles per hour, its speed would be 300 miles per hour. The VELOCITY of the aircraft would be 300 miles per hour EAST. Because velocity is a vector quantity with magnitude and direction, there is more than one way to change velocity. The speed can be changed, the direction can be changed, or both can be changed. (See fig. 3–5.)

Velocity is uniform only when equal distances along a

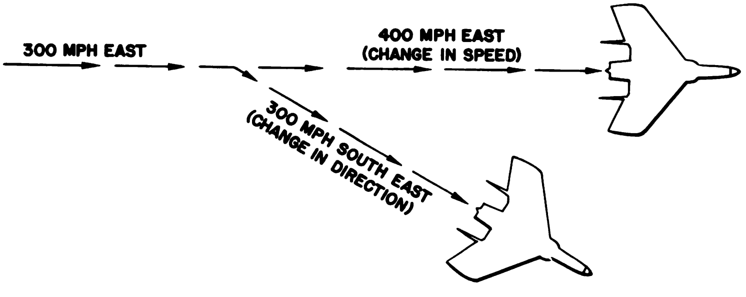


Figure 3–5.—Change in velocity.

straight line are traveled in equal intervals of time. Symbolically, if d is the distance covered in time t, the velocity is

$$v=\frac{d}{t}$$

How long does it take an aircraft traveling at 200 miles per hour to travel 300 miles?

$$t=\frac{300\text{ mi.}}{200\text{ mi./hr.}}=\frac{3}{2}\text{ hr.}=1\text{ hr. }30\text{ min.}$$

Remember that both speed and direction are involved in velocity. When substituting in the velocity equation, however, only magnitude of velocity is used.

RELATIVE VELOCITY.—In discussing velocity, it is necessary to have a point of reference. If two aircraft are traveling with the same velocity (300 mi./hr. north) and are separated by five miles of distance, they obviously will never make contact. But consider a situation where one aircraft is flying north at 300 miles per hour and the other in front is flying north at 200 miles per hour. The faster of the two will overcome the slower with a rate of change of range of 100 miles per hour. Now consider one aircraft flying south at 300 miles per hour and another flying north at 300 miles per hour. What is the relative velocity between the two or the rate of change of range? *Answer:* 600 miles per hour.

If the aircraft flying north was taken as the point of reference, then the other aircraft would have a relative velocity of 600 miles per hour south. In discussions on the fire control problem, the aircraft is often considered as a gun platform. If such is the case, then the velocity of a target would always be relative to the gun platform.

LINEAR ACCELERATION.—When the velocity of a moving body increases continuously as the motion proceeds, the body is said to move with accelerated motion or to have an ACCELERATION. For example, suppose that the velocity of an automobile increases steadily from 30 miles per hour to 60 miles per hour in 3 minutes. During each minute of the 3-minute interval the velocity increases by 10 miles per hour per minute. Therefore, the velocity increases at the rate of 10 miles per hour per minute. This rate of change of velocity with respect to time is called acceleration. Acceleration may be either positive or negative, positive acceleration meaning an increase in velocity and negative acceleration a decrease. Negative acceleration is also called deceleration or retardation.

The equation for average acceleration is

$$a=\frac{V_2-V_1}{t}$$

where a is acceleration, V_1 starting velocity, V_2 final velocity, and t elapsed time. The above equation is true only for uniform changes in velocity.

One of the most common examples of motion with a nearly constant acceleration is that of a body falling toward the earth. In a vacuum, all bodies—regardless of their size or weight—fall with the same acceleration. Acceleration of a freely falling body is known as acceleration due to gravity, which is nearly 32 feet per second per second near the earth's surface. Usually the letter g is used to represent this acceleration due to gravity. Because of its effect on a projectile in flight, the force of gravity must be taken into account in the resolution of the fire control problem.

ANGULAR VELOCITY.—The concepts of velocity and acceleration that have been presented so far have dealt solely with linear motion. As was pointed out previously, relative motion is composed of both linear motion and angular or rotational motion. The ideas of linear velocity and acceleration presented in the preceding section have their exact parallels in rotational motion. In both cases, displacement with respect to elapsed time is known as velocity, and a change in velocity with respect to time is known as acceleration.

Although the equation of angular motion takes on a simpler form when the angular velocity is expressed in radians per second, the expressions revolutions per second (r. p. s.) or revolutions per minute (r. p. m.) are also commonly encountered. As explained in the chapter on trigonometry in

Advanced Mathematics, Volume 1, NavPers 10071, there are 2π radians in one revolution. The number of radians per second, therefore, equals 2π times the number of revolutions per second or $2\pi/60$ times the number of revolutions per minute.

The number of revolutions or cycles per second is usually referred to as the FREQUENCY. The quantity angular velocity $2\pi f$ is represented by the symbol ω (omega). Therefore,

$$\omega = 2\pi f.$$

There are two common methods for measuring angular velocity. In the first method, a revolution counter is held against the end of a rotating shaft and the number of revolutions during a time interval is noted. The time and the displacement are thus measured and the ratio gives the angular velocity. In the second method, the angular velocity is measured directly by a tachometer. Most tachometers, however, are calibrated in revolutions per minute rather than in radians per second. The common automobile speedometer is a good example of a tachometer calibrated in miles per hour.

The preceding section on linear motion shows that if a body is moving with constant velocity the distance covered in any period of time is the velocity multiplied by the time. An exact analogy occurs in circular motion. Let θ (theta) be the angle or the angular distance covered. Then the equation for the angular distance or degrees through which the body rotates is

$$\theta = 2\pi f t = \omega t$$

where θ is the total angular distance covered expressed in degrees, revolutions or radians; $2\pi f$ or ω the angular velocity in degrees, revolutions, or radians per second; and t the elapsed time in seconds.

ANGULAR ACCELERATION.—Newton's first law of motion states that "every body continues in a state of rest or of motion in a straight line unless compelled by external force to change that state." Thus, a body is accelerated when a continuous external force is applied to the body either at rest or in uniform motion. If the direction of the external force is in line with the motion of the body and in the same direction, the body is speeded up (accelerated). If the direction of the external force is in line with the motion of the body and in the opposite direction, the body is slowed down (decelerated). If any component of the external force is not in line with the motion of the body, the body is turned from its path.

No doubt you have at some time performed the experiment of tying a stone or weight to a cord and whirling it in a circle. While the object is revolving, there is a pull exerted on your hand. Conversely, your hand must exert an inward pull on the object. This pull of an object whirled around in a fixed circle is due to radial acceleration, as it is called in physics.

If a rock starts from rest and in t seconds acquires an angular speed of ω radians per second, assuming that the process has been done at a uniform rate, it can be said that the angular acceleration α (alpha) expressed in radians per second is

$$\alpha=\frac{\omega}{t}$$

Note: This is angular acceleration and not the acceleration of the rock around the circumference of the circle.

According to Newton's second law, a force must be exerted on a moving object to make it follow a curved, instead of a straight, path. The necessary force is proportional to rate of change of momentum produced. This force is in the same direction as radial acceleration, which is inward. It is called CENTRIPETAL FORCE. The name "centripetal" literally means center-seeking. It is the pull which your hand must exert on the string. The opposite or reaction force to this is CENTRIFUGAL force which means center-fleeing.

Recall that velocity is a vector and that a vector has magnitude and direction. If a body moves at a constant speed around the circumference of a circle, its velocity (v) is always varying because the direction of the velocity is changing. As stated previously, it can be shown that acceleration is toward the center and that the centripetal acceleration (a) is equal to v^2/r, where v is the velocity tangent to the circumference and r is the radius of the circle.

By substituting v^2/r for a in Newton's second law ($F=ma$), the equation becomes:

$$F=\frac{mv^2}{r}$$

This equation is given to point out the factors influencing the centrifugal force. Recall that centrifugal force is opposite and equal to centripetal force. Notice that the force of centrifugal action increase directly with the mass and as the square of the velocity. Thus, an increase in velocity of three times produces nine times the centrifugal force.

In aviation, the acceleration produced when a plane pulls out of a dive is an extremely important factor. Electronic equipment must be designed to withstand the physical strain of centrifugal force in planes and guided missiles. The peak acceleration due to a quick turn or pullout is measured ing g's. One g is 32 feet per second per second. A 10-g pullout from a dive, therefore, means that the acceleration is 10 times that caused by gravity, thus a 5-pound weight would pull with a force of 50 pounds in a 10-g dive. Electronic equipment for use in guided missiles must not produce distortion when accelerated up to 40 g's.

Further application of centrifugal force is found in the gyroscope. The gyroscope is the basic element in such instruments as the gyrocompass, the gyropilot for airplanes and ships, and certain types of aviation fire control systems.

RELATIVE MOTION CONCEPT

The actual path in space traced by an aircraft as viewed by an imaginary observer at some fixed point in space is, in general, a very different appearing curve when viewed from another aircraft. In figure 3–6, let the horizontal curve (right to left) represent the path of a target aircraft as viewed by this spatial observer. The vertical curve (bottom to top) represents that path of fighter plane or airborne gun platform. The t numbers on both curves represent corresponding intervals of time. The distance or range at each interval of time is represented by r. The angle τ (tau) measured from the gun platform bow to the gun-target line, is called the ANGLE-OFF OF THE TARGET or simply angle-off.

The path of the target as viewed by the observer is called the "air course," while the path of the target as viewed from the gun platform is spoken of as the "relative course." Figure 3–6 shows the air course of both target and gun platform. These curves represent the ACTUAL motion in space. Notice as time progresses, the range becomes smaller, and the angle decreases and then changes from right horizontal to left horizontal.

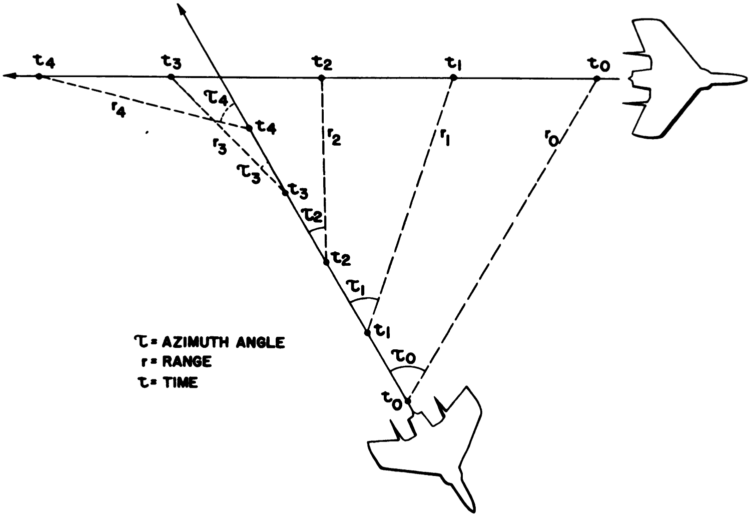


Figure 3–6.—Air course of target aircraft.

In the solution of the air-to-air fire control problem the actual course of either target or gun platform is of much less importance than the relative course. The reason for this is that the correct lead angle for obtaining a hit depends upon the relative motion between the two aircraft.

Because the relative course is the important course, let us consider the path of the targe relative to the gun platform.

This path may be determined by using a gun platform as reference and measuring the range angle-off of the target for several points. A smooth curve is then drawn through these points resulting in figure 3–7.

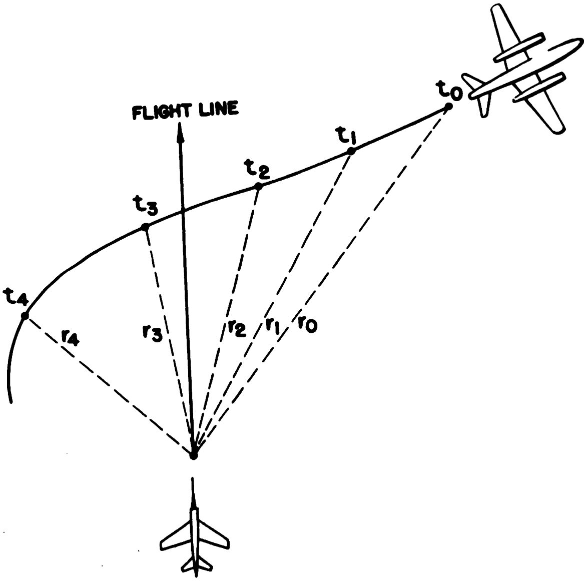


Figure 3–7.—Relative course of target aircraft.

In figure 3–7, r_0 distance is the same as the r_0 distance in figure 3–6, as are all corresponding distances. Angle τ_0 in figure 3–6 is the same as the angle formed between the flight line and the line from the reference to τ_0 in figure 3–7. The only difference between the two figures is the point used as references. As you can see, then, the actual path in space traced by an aircraft as viewed by an imaginary observer at some fixed point in space is, in general, a very different appearing curve when viewed from another aircraft. Figure 3–8 shows both the air and relative courses of a fighter pursuing a bomber.

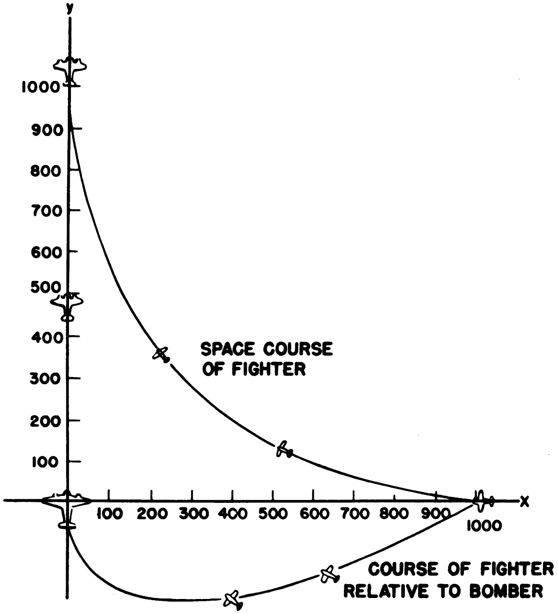


Figure 3–8.—Air and relative courses of fighter pursuing a bomber.

FUTURE TARGET POSITION

The ability to determine the future position of the target when the projectile strikes is in essence a solution to the fire control problem. There are many factors which contribute to the determination of this future position. To facilitate your understanding of this fire control problem, consider the following three general cases.

GUN PLATFORM AND TARGET BOTH STATIONARY.—First consider the hypothetical case of a ballistically perfect stationary gun firing at a stationary target in a vacuum and where the projectile is not subject to effect of gravity. The fire control problem in this case is merely to aim the gun so that the axis of its bore intersects the target. Since there is no force acting on the projectile except that which expelled it from the gun, it will travel along a straight line and hit the target.

In any actual case, such as firing at a stationary target on a target range, the effects of gravity, and sometimes wind, are exerted on the projectile and cause it to depart from its straight-line flight. Gravity causes the projectile to travel along the parabolic trajectory. To compensate for its effect, the point of aim must be slightly above the target. Military rifles have this gravity compensating feature built into them in the form of an adjustable sight whereby the rear sight peephole is raised as the firing distance increases. When the target is alined with the front and rear sights, the axis of the gun barrel is inclined sufficiently above the horizontal to compensate for the effect of gravity.

The effect of wind on the projectile is apparent, especially when firing at a distant target, but counteracting it becomes even more complicated when one realizes that the projectile travels at a continuously decreasing velocity, due to air resistance. Obviously, the slower a projectile travels, the greater will be the effect of the wind in deflecting it from its course. Nevertheless, in the stationary firing problem, the amount of deflection produced by the wind can be determined after firing a few rounds by observing how far from the bull's-eye the bullets tend to hit. Aiming the rifle this amount of deflection in an equal and opposite direction from the bull's-eye, results in compensating for the effect of wind.

The fire control problem in the stationary gun and stationary target situation is very simple and the angle at which one must aim the gun in order to hit the target is easily determined.

GUN PLATFORM STATIONARY AND TARGET MOVING.—In the case of a stationary gun platform and moving target, the situation becomes more complicated. In addition to the effects of wind and gravity, one must fortell where the target will be when the bullet arrives to hit it—THE FUTURE TARGET POSITION.

Here, as in duck shooting, it is necessary to "lead" the target. The aim must be ahead of the duck by an angle corresponding to the distance the bird is expected to fly between the instant of firing and the time it takes the shot to travel the distance between the gun and the bird. This idea may also be expressed by: "The present position data are used to estimate the future position of the target based upon the rates of change of present position data." In duck shooting, as the bird flies at a relatively slow speed compared to the speed of the shot, the determination of the necessary lead angle is not too difficult and is easily estimated after some experience.

This case is essentially the problem of antiaircraft fire, but also applies to the fighter pilot's problem of correctly aiming forward firing guns. The basic aiming allowance here is for the target's relative motion during the projectile's time in flight and is called the KINEMATIC lead. Additional slight modifications of the gun bore's position must also be made to allow for gravity drop. There are, therefore, two factors to be considered when aiming—the KINEMATIC LEAD and the GRAVITY LEAD.

This case is also similar to the problem of precision bombing or aircraft strafing. In these situations negative leads are required and the problem is actually "gun platform moving and target stationary." Although similar, there is an important physical difference. In the strafing problem, the velocity of the gun platform is added to the muzzle velocity to obtain the initial velocity of the projectile. The projectile velocity is important in determining time of flight, and time of flight is one of the determining factors in establishing the point of aim. Therefore, there is a slightly different method of solution of the antiaircraft problem and the strafing problem. In the air-to-air problem the initial velocity of the missile will be established as in the strafing problem.

GUN PLATFORM AND TARGET BOTH MOVING.—In the case of air-to-air gunnery where two aircraft are traveling at near sonic speed and where their relative velocity begins to approach the order of the velocity of the projectiles themselves, the problem of fire control becomes much more difficult. The necessary lead angle can no longer be mentally estimated as in the case of the duck hunter, but must be continuously and accurately computed.

While this is the most complex of three general cases, it is very similar to the preceding case of gun stationary and target moving. This case is generally solved by the ANGULAR RATE of travel prediction for high speed; and for lower speed involving surface ships and submarines, LINEAR SPEED prediction is utilized. In aviation fire control the ANGULAR RATE OF TRAVEL prediction is the method used.

Air-to-Air Fire Control

By use of the concept of relative motion, and by considering the gun stationary and the target moving about it, the air-to-air problem can be resolved to the stationary gun platform and moving target case. Using the angular rate prediction method, two lead angles are material in considering the problem of a bullet leaving a moving fighter aircraft and striking a moving target. These are the lead angles necessary to compensate for the effects of the relative motion between the gun and the target (kinematic), and to compensate for the ballistic effects on the projectile during its flight.

While there are many factors that go into its determination, the lead angle necessary at any instant of time may essentially be considered equal to the product of the angular velocity of the target with respect to the firing aircraft and the time of flight of the bullet. Among the factors and their effects contributing to this determination of the lead angle are:

RANGE.—Range may be divided into two categories—present range (r) and future range (r_f). As pointed out in the previous section, present range may be determined optically or by radar. Future range is the range of the target at the time of impact with the bullet. Future range is one of the factors that it is necessary to compute in the solution of the fire control problem.

TIME OF FLIGHT.—Time of flight (t_f) is the time taken for the projectile to cover the range from the firing point to the future position. If the present range is the target's position at the time of firing, then the time of flight is the time for the bullet to travel the distance of the future range. But, the computation of future range is dependent upon a knowledge of the time of flight. Hence, it is seen that time of flight and future range are interdependent on one another. The future angular position of the target is also dependent on the time it takes for the missile to reach the target.

If the projectile were fired at a target in a perfect vacuum, and if the projectile were not subject to deflection by ballistics factors, it would move along a straight line at a constant velocity. For such a hypothetical situation

$$\text{Time of flight } (t_f)=\frac{\text{Range}}{\text{Muzzle velocity}}=\frac{r_f}{V_0}$$

In practice, however, the influence of gravity causes the projectile to move along a parabolic trajectory and the actual distance it travels must of necessity be greater than the straight-line distance r_f. Since the projectile is traveling through air, it is decelerated by the air resistance. The amount of deceleration is determined by the air density and size and shape or contour of the projectile. Another factor affecting time of flight is the true airspeed of the aircraft which must effectively be added to the gun's muzzle velocity to determine the deceleration caused by air resistance. From these factors the average velocity of the projectile, referring to the straight-line distance r_f, must be computed to obtain time of flight. In practice the empirical equation for the time of flight becomes

$$\text{Time of flight}=\frac{\text{Range}}{\text{Muzzle velocity}}+\text{Lost time of flight}$$

or

$$t_f=\frac{r_f}{V_0}+t_L$$

Relative velocity of target.—The relative velocity of the target may be broken down into two components—range rate and angular rate. Range rate, as shown previously, is the rate of change of range in respect to time. If a radar is used for ranging, the range rate may readily be determined by electronic means. Because the gun platform is used as reference, the range rate will be the relative rate of change between target and gun. If the range rate is multiplied by the time of flight, the product is the total change in range by the time the bullet hits the target. Adding this product to the present range results in the future range of the target at the time when the bullet hits the target.

The angular velocity of the target with respect to the firing aircraft means the rate at which the line joining the target and the firing aircraft is turning or rotating, assuming the firing aircraft to be still. Thus, if the relative angular velocity is 5 degrees per second at any particular instant of time and the time of flight of the bullet to the predicted target position is ½ second at that same instant, the necessary lead angle at that instant will be 2½ degrees.

Because of the three dimensions involved in the air-to-air fire control problem, angular velocity, or angular rate, is at times divided into two components. These are AZIMUTH ANGULAR VELOCITY and ELEVATION ANGULAR VELOCITY.

In the optical fire control equipment the angular velocity of the target is determined during the tracking phase when the pilot flies a coordinated turn. In such a turn, the gyroscope of the sight unit is offset from its zero position by the aircraft's angular velocity in space. This offset is the result of the inherent rigidity of a gyroscope. There is only one gyroscope, but because of the method of sight construction the gyroscope determines both azimuth and elevation portions of angular velocity.

In the radar director system, measurement of angular velocity is accomplished by means of two rate gyroscopes located in the antenna assembly. The AZIMUTH-RATE GYRO precesses whenever the azimuth component of the antenna angle changes, while the ELEVATION-RATE GYRO precesses only when the elevation component of the antenna angle changes. The degree of precession of these rate gyros is proportional to the rate at which these angular components are changing.

PRESENT LEAD ANGLE.—The present lead angle is the angle at any instant of time. The present lead angle is compared with the lead angle furnished by the computer to determine whether or not the gun platform is pointed in the right direction. The present lead angle may also consist of two components—the azimuth and elevation portions.

GRAPHICAL RESOLUTION OF KINEMATIC LEAD ANGLES

As an example of the graphical resolution of the kinematic lead angle, let us consider the case of a fighter flying a lead pursuit course towards a target when both target and gun platform are in a single horizontal plane; that is, target and gun at the same altitude. The conclusion drawn from this case will then be generalized in three dimensions. A typical lead pursuit attack in a horizontal plane is illustrated in figure 3–9.

Two-Dimensional Case

Air course.—In figure 3–9, the fighter is at a present position *G*, the target is at a present position *T*, and the present range between the two aircraft is *r*. It is assumed that the fighter is on a lead pursuit curve; that is, a projectile fired at (this) present time will arrive at the future position on

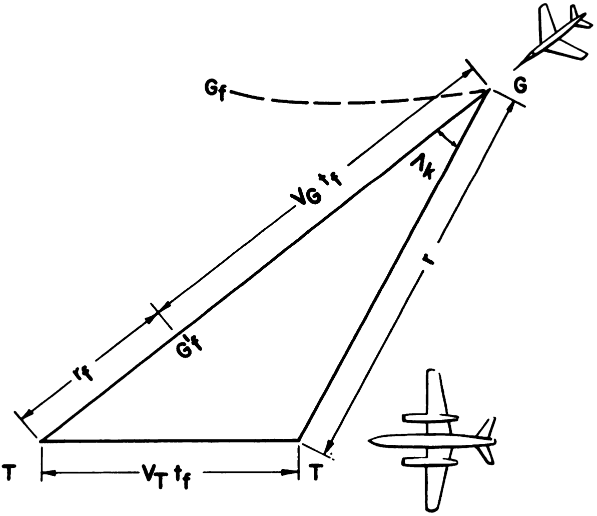


Figure 3–9.—Lead pursuit course in the horizontal plane.

the target, T_f, with the target and will score a hit. The kinematic lead angle is denoted by using the Greek letter lambda (Λ_k).

As shown in figure 3–9, the fighter will be turning at the time of firing. However, such fighter motion will have no effect on the flight of the projectile. Only the direction and speed of the fighter at the time of firing affect the flight of the projectile. So far as the projectile is concerned, it is assumed that the fighter continues to fly in the same direction as at the time of firing, although in reality this is not true. The actual position of the fighter when the projectile hits the target will be G_f. For the purpose of calculation it is assumed that the future position of the fighter is G'_f which lies on the flight path of the projectile.

Referring once again to figure 3–9, the target flies from T to T_f while the projectile travels from G to T_f and the fighter is assumed to fly from G to G'_f. The time of flight of the projectile is denoted by t_f. (Be careful not to confuse this with T_f—target future position.) Therefore, the target flies a distance equal to its velocity multiplied by the flight time of the projectile or $V_T t_f$. The fighter flies a distance equal to its velocity multiplied by the flight time of the projectile or $V_G t_f$. The distance between the fighter and the target when the projectile hits the target is called the future range T'_f. This is also the distance or range the projectile has attained in front of the fighter during its time of flight.

Relative course.—Now let us consider the relative motion of the target in respect to the fighter. The relative course will be a straight-line course at a constant speed. The initial range is r, and t_f seconds later the range will be r_f. Figure 3–10 shows this relative course.

In figure 3–10, the relative position of the fighter with respect to itself remains fixed at G throughout the course. The present position of the target is T. The target appears to fly in a straight line (at a constant speed, V_T) towards position T_f, which is the relative position of the target t_f seconds after the present time. The relative distance it flies is $V_T t_f$. The future position of the target T_f is at

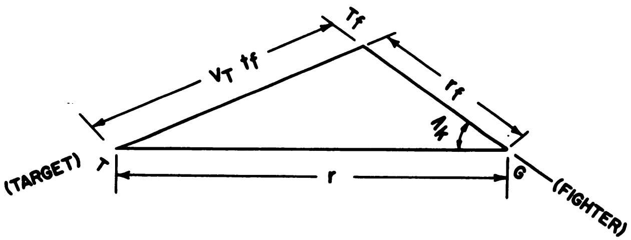


Figure 3–10.—Relative motion of target to fighter on pursuit course.

range r_f from the fighter and the target is the line GT, the length of which is the present range r. The present kinematic lead angle, Λ_k, is the angle between the line of sight and the line of flight of the fighter.

Three-Dimensional Case

Let us now consider the three-dimensional case. In this case the fighter and target may be climbing or diving, but it is still assumed that the target is flying a straight line, constant speed course. The three-dimensional situation of a fighter attacking a target is shown in figure 3–11.

In figure 3–11, the target flies horizontally from T to T_f while the fighter is diving on the target. Notice that the target's course is intersected at T_f by the extension of the fighter course.

This problem differs from the preceding two-dimensional case in that the determination of the kinematic lead angle is dependent upon two factors—the azimuth component, Λ_{kA}, and the elevation component, Λ_{kE}. As in the single plane case, the lead angle is dependent upon angular velocity. When using the radar system for computing the lead, the angular velocity of the target is determined by rate of gyroscopes positioned on the antenna. In the optical system, airstream direction detectors are used for measuring the angle of attack and the angle of skid. In both systems the information concerning both the elevation and azimuth angles is fed to a computer where the other factors are added. The result is computation of a correct lead angle resulting

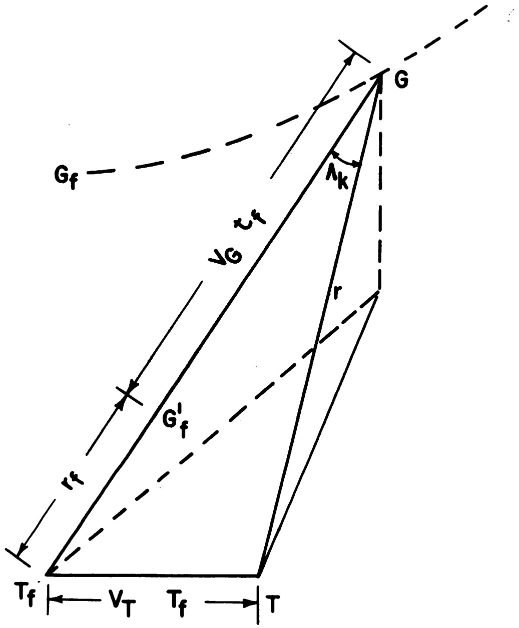


Figure 3–11.—Three-dimensional view of pursuit course.

in the projectiles arriving at T_f at the same instant as the target.

ADDITION OF KINEMATIC AND BALLISTICS LEAD ANGLES

The preceding discussion of the kinematic lead angles (lead angles due to the relative motion of the gun platform and the target) was developed under the assumption that the flight path of the projectile is a straight line in space. Actually the projectile travels along a slightly curved flight path, or trajectory. This departure from a straight-line flight path is due to the influence of gravity, the fact that the projectile may not be fired directly into the airstream, and other ballistic factors. The angular deflection resulting from these causes are called ballistics lead angles. The ballistics lead angles are generally much smaller than the kinematic lead angles, but must be taken into account. Because of the differences in methods, the addition of the ballistics and kinematic lead angles will be discussed under three separate conditions: The disturbed reticle system, the turret control system, and the fixed gun director system.

DISTURBED RETICLE SYSTEM.—It is important to bear in mind that in this system all the factors, both kinematic and ballistics, are utilized to offset and change the sensitivity of the gyro of the sight unit. This gyro offset is reflected to the eyes of the pilot as the calculated lead and is the angle between the gyro image held on the target and the fixed image.

In the disturbed reticle (optical) system, the gravity lead component is proportional to the projectile's time of flight divided by the projectile's average velocity. In computing TIME OF FLIGHT, besides range and range rate, the other factor is the average velocity of the projectile.

The projectile's AVERAGE VELOCITY is defined as the muzzle velocity less the loss in velocity due to air drag on the projectile. This air drag loss is calculated within the computer by means of an empirical formula involving the following elements: Local air pressure, aircraft's velocity, time of flight, and certain ballistic constants determined by experiment for each type of ammunition.

Notice that the computation of time of flight depends upon the average velocity of the projectile, and this velocity is, in turn, dependent on time of flight. Thus the computation of one factor is dependent on a second factor whose computation is dependent on the first factor. This interdependence would appear to make the problem impossible of solution, but practically the required results are obtained by making both calculations simultaneously.

The computed gravity lead is also acted upon by an accelerometer within the computer by electrical means. This accelerometer measures the *g*'s pull on the projectile and modifies the gravity lead computation to compensate for this *g*'s pull. This corrected gravity lead is then added to the kinematic lead angle in the computer to obtain the total lead angle and to deflect the gyro accordingly.

TURRET CONTROL SYSTEM.—In this system the ballistics lead angle is divided into two components—azimuth (horizontal) and elevation (vertical).

The ELEVATION COMPONENT consists of three distinct parts: The vertical deflection part, the gravity part, and the elevation component of windage jump. The first of these, the vertical deflection, is the sum of all the ballistic forces acting on the projectile, with the exception of gravity and windage jump. The vertical deflection obtained is the product of a group of empirical functions which are calculated to match the ballistics tables for the guns. These functions include the correction that must be made for varying air density, true airspeed, gun position, muzzle velocity, and time of flight.

Vertical windage jump is the name given to the elevation component of the combined effect of the cross wind force on the projectile and the deflection caused by the spin of the projectile. Gravity deflection is due, of course, to the effects of gravity and is dependent upon the time of flight of the projectile and the gun elevation position. (Recall from the preceding chapter how the angle of departure affected the trajectory of a projectile.)

The AZIMUTH COMPONENT consists of two parts: The horizontal deflection and the horizontal windage jump. It is also necessary to correct the total horizontal ballistics angle for variations in the elevation position of the guns. As with the vertical deflection, the horizontal deflection is obtained as the product of a group of empirical functions which correct for varying air density, true airspeed, muzzle velocity, gun position, and time of flight.

Horizontal windage jump is the name given to the azimuth component of the combined effect of cross wind on the projectile and the deflection caused by the spin of the projectile.

The total horizontal ballistics angle must also be compensated for variations in the azimuth arc of the guns at different elevation angles. As the turret revolves in azimuth, a point on the bore axis of the guns will describe an arc in space. If the guns are pointed in a straight horizontal direction, this arc will have a greater length for a given angle of azimuth rotation than if the guns are given some other angle of elevation. Consequently, to secure the same deflection at high elevations as obtained in the horizontal plane, it is necessary to rotate the guns in azimuth through a greater angle.

In order to obtain the total lead angle, the total ballistics lead angle must be added to the kinematic lead angle. The turret position at the time of firing the guns is expressed in terms of its angular deflection in azimuth and elevation with reference to a scanner-target line. Therefore, in order to obtain the correct turret or gun position, the total lead angle must be added to the angular position of the scanner.

In practice, scanner position information is delivered to the computer. Then the total lead-angle information is added to scanner position information. The output from this addition is used as the means to automatically control the position of the turret.

Fixed gun director system.—This type of system divides the problem into three computations: Time of flight, gravity deflection, and relative velocity lead angle (kinematic). As pointed out previously, time of flight is essentially a combination of ballistics and kinematic factors. After computation the three components are combined to predict the correct lead angle.

In this system the gravity deflection or ballistic lead angle has two components—the azimuth component, Λ_{BA}, and an elevation component, Λ_{BE}. These components must be combined with the azimuth and elevation components of the kinematic lead angle Λ_{kA} and Λ_{kE}, to give the components of the total lead angle Λ_A and Λ_E. The exact combination of these components is given by complicated trigonometric expressions. However, an approximation by simple addition of these components will usually suffice for the accuracies required in airborne fire control.

As with guns and rockets, whether a bomb or other missile strikes a target depends on the aircraft being in the proper position at the proper moment. Accordingly, all bombsights or bomb directors furnish information which will assure a hit if the pilot will put his plane at the point indicated, and if the missile is dropped in accordance with the predetermined ballistic formula. As the distance of altitude increases, the problem of hitting the target increases.

Methods of Bombing

A number of types of bombing attacks have been developed, each with particular advantages and disadvantages, and each designed to fit certain needs. In general, determination of the required type of bombing depends on such factors as (1) nature of target, (2) nature of ground and air defense, (3) type of damage desired on the target, (4) weather conditions over the target, and (5) distance to the target. To meet these tactical requirements, a number of general types of bombing have been evolved for Navy use.

These methods of bombing may be divided into the following categories: High level horizontal bombing, low level horizontal bombing, dive bombing, toss bombing, and loft bombing. LEVEL BOMBING consists of the aircraft flying a straight horizontal line during its bombing run. Generally, if the bombing is done at altitudes below 5,000 feet, it is considered LOW LEVEL BOMBING. When bombing from this low level, the air resistance operating on the bomb during its fall is negligible by comparison with that resistance obtained at much higher altitudes. The altitude range extending from 5,000 feet up to the ceiling of the aircraft is referred to as HIGH LEVEL BOMBING.

High Level Bombing

VACUUM TRAJECTORY.—In our investigation of high level bombing, first consider the action of a freely falling body in a vacuum. Referring to figure 3–12, suppose that the bomber travels the line from O to O' with a constant speed V knots. Suppose also that the bomber requires t_f seconds to cover this distance, that the bomb is released at point O, and that the bomber is H distance above the target at T. Since no air resistance is presumed to be acting, the horizontal component of the bomb's velocity will also be the bomber's velocity at all points of its trajectory. Thus it can be seen that during its fall the bomb will remain vertically below the aircraft. The space path of the bomb is shown in figure 3–12 while its path relative to the bombardier is simply a vertical straight line.

Since the distance traveled horizontally is equal to velocity multiplied by time, the bomb's horizontal travel, or range R, is equal to Vt_f. The angle formed at the time of release between the true vertical and the line of sight is called the RANGE ANGLE. The symbol for the range angle is the Greek letter ϕ (phi). (See fig. 3–12.)

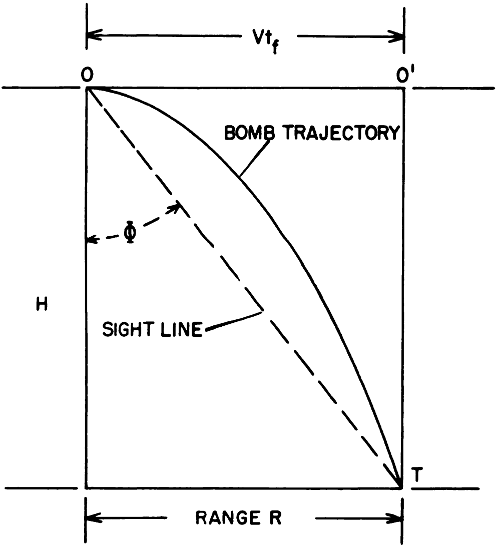


Figure 3–12.—Vacuum trajectory for bomb.

It can be shown by trigonometry that the range angle is

$$\phi=\tan^{-1}\left(V\sqrt{\frac{2}{gH}}\right)$$

where V=horizontal velocity
g=acceleration due to gravity
H=release altitude

This relationship is given to draw attention to the fact that the angle is dependent upon two variables (g is constant). Both of these variables, H and V, can be measured. Therefore, to hit a target when flying straight and level at a predetermined altitude and speed, it is only necessary, assuming air resistance on the bomb during its fall to be negligible, to drop the bomb as soon as the target appears at the angle ϕ from the vertical.

AIR TRAJECTORY UNDER NO WIND.—Let us now consider the bombing problem in air but under no wind conditions. The difference between the two situations is the effects of air resistance which has two important effects on the path of the bomb. First, it decreases the vertical velocity of the bomb, thereby increasing the time of fall. Second, it diminishes the horizontal velocity of the bomb, thus causing the bomb to trail behind the vertical line of the bomber.

The exact effect of air resistance on a particular bomb depends on the type of bomb as well as the release conditions. For example, a small, streamlined bomb is less affected by air resistance than a large, irregularly shaped bomb of equal weight. Consequently, the small bomb falls faster and its time of fall is less. The effect of air resistance on any bomb is determined by the bomb's "ballistic coefficient," an empirical quantity. The ballistic coefficient for any bomb type is obtained from tables determined from actual bomb drops. Therefore, in addition to altitude above target and vertical velocity, the time of fall for a bomb dropped in air is dependent upon the ballistic coefficient.

The effect on range is that the bomb no longer remains beneath the airplane while falling, and that range no longer equals time of fall (t_f) multiplied by airplane groundspeed (V). This is because the air resists the horizontal motion

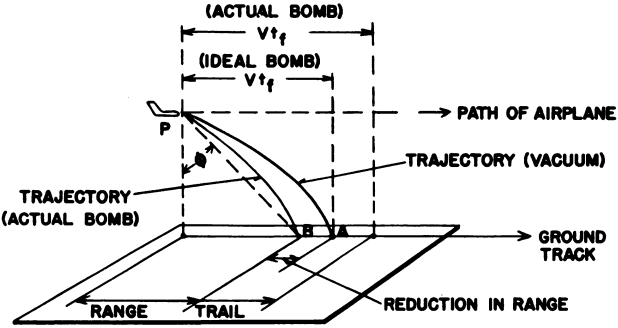


Figure 3–13.—Effect of air resistance on bomb trajectory.

of the bomb, causing a gradual reduction of its horizontal velocity. The effect of the increase in t_f is more than offset by the decrease in the bomb's horizontal velocity. Figure 3–13 shows the effect of air resistance on bomb trajectory, and for comparison the trajectory of an ideal bomb in a vacuum.

With a constant airspeed and course, the horizontal distance that the bomb has lagged behind the airplane at the instant of impact is called TRAIL (r). The amount of trail is governed by the aircraft's airspeed at the time of release. In addition it is dependent upon the altitude of release and, of course, the ballistic coefficient of the bomb. Trail values for each type of bomb are determined during the calibration of the bomb at the proving ground and are set forth in tabular form, trail being given in angular measure (mils). In bombing practice the value of an angle in bombing mils may be found by dividing the distance on the ground by 1/1000 of the altitude. The mil in bombing does not have the same interpretation as used in gunnery.

Figure 3–13 shows that the range R of the bomb dropped in air is obtained by subtracting the linear trail value from the vacuum range. An ideal bomb dropped from point P hits the ground at impact point A. During the time of fall, the airplane travels distance Vt_f, where t_f is for the ideal bomb. Thus, at impact, the airplane is directly over point A. An actual bomb dropped from point P hits the ground at impact point B because of air resistance. Since t_f for the actual bomb is greater than that for the ideal bomb, the airplane travels the distance Vt_f (actual) during the time of fall. Thus, trail includes not only the reduction range, but also the travel of the airplane during the additional time of fall.

DRIFT AND TARGET MOTION.—Up to this point the discussion of the bombing problem has assumed the conditions of still air and a stationary target. Now let us consider the problem with the introduction of wind. Later in this section we will consider target motion. Assuming a standard air structure, the wind will be considered as moving horizontally only, with constant speed and direction at all points of the bomb trajectory. Thus, we shall have no vertical component of wind to contend with.

As pointed out in the ballistics chapter, the principal effects of either a headwind or a tailwind is the change made in the closing speed of the aircraft. Our problem now is to consider the effects of a wind other than a headwind or tailwind. This is shown in the diagram of figure 3–14.

In figure 3–14 the line AD gives the direction in which the aircraft is being steered, namely the plane's HEADING. The vector V is then the velocity of the bomber with respect to the air. The wind vector W, representing the velocity of the air with respect to the ground, combines with V to give V_c, the velocity of the bomber with respect to the ground. The line AA is the line of action of vector V_c and is called the bomber's TRACK. The angle θ (theta) formed by the heading and the track, is called the DRIFT ANGLE.

There are three important points to be noted in figure 3–14. First of all, the direction of the trail (r). The trail always lies in a line through the forward-aft line of the aircraft and is independent of the wind. Second, it will be noted that because of this fact the bomber, to obtain a hit, must fly so that its track will pass to one side of the target by the amount $P'T$. (NOTE: $P'T$ equals $r \sin \theta$.) This quantity is called the CROSS TRAIL.

Third, as figure 3–14 shows, the bomb will strike, unless a special correction is made, not at the target T but at a slight distance forward at B. To account for this, it must

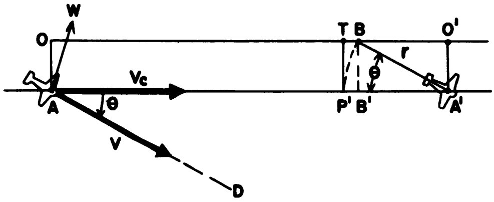


Figure 3–14.—Drift angle and trail.

be remembered the trail (r) is independent of wind and therefore θ. Thus, only when θ is zero, namely for flight in still air, upwind or downwind along OO' will the bomb strike at T. Therefore, to secure a hit at T, the bomb should be released when the aircraft is the distance TB back from A along the track. This factor is called the RANGE COMPONENT OF CROSS TRAIL. It is usually very small, being obscured by other bombing errors, and for this reason is sometimes omitted from consideration in constructing bombsights.

So far, we have considered the target to be stationary. In order to take target motion into account we may resolve the target velocity into components along and perpendicular to the plane's heading. Then that component of the target's motion along the plane's heading gives the same effect as a headwind or a tailwind depending upon whether its direction is the same or the direct opposite of the aircrafts. Similarly, the component of the target's motion across the plane's heading may be considered as a cross wind and absorbed in the solution for the drift angle by combining it with the wind vector. Hence the effect of target motion is merely to change the values of aircraft velocity and wind velocities (V and W) and then to regard the target stationary as before. The correct range or dropping angle ϕ is a function of the trail, altitude above the target, time of flight of the bomb, and the closing speed, V_c.

RELEASE POINT COMPUTATION.—The release point problem consists of determining the course to fly and the point along that course at which to release the bomb to hit the target.

Release point computation is based on solution of the tracking and bomb ballistic problems.

Tracking establishes the position and relative motion between the airplane and the target. Tracking data are obtained by tracking the aim point, which may be either the target or an aim point displaced from the target. A displaced aim point can only be tracked when the target is stationary, and the position of the target with respect to the aim point is known. Position data establish the initial position of the aim point with respect to the airplane, and the rates establish continuously the change in position of the airplane relative to the aim point.

As noted before, the correct range or dropping angle ϕ is a function of the trail, altitude above the target, time of flight of the bomb, and the closing speed. Previous to this, there is the problem of establishing the proper track parallel to a collision course with the target, and at a distance equal to the cross trail.

A bombsight computer for determining ϕ will then have as inputs r, H, t_f, and V_c. The trail, r, is obtained from trail tables, wherein it is given as a function of altitude, airspeed, and bomb ballistic coefficient, and can thus be set in by the bombardier. The altitude input is available from an altimeter while time of flight is tabulated as a function of altitude. Closing speed is obtained by tracking the target with a telescope, keeping the cross wire continuously on the target. This method of computing the release point is called the RANGE ANGLE METHOD.

Modern bombsights have the telescope mechanically stabilized with vertical and horizontal gyros so that physical reference lines are available from which to measure the range and drift angles. The drift angle θ can be obtained by having the bombsight always pointed directly at the target. Then the angle between the fore-aft axis of the aircraft and the direction in which the sight is pointing will be the drift angle providing the heading of the plane is correct for the wind conditions prevailing. The bombardier establishes the angle of drift by positioning the telescope cross wire so that the target moves along the vertical cross wire. If the plane's heading is slightly off, the target will drift off the wire. By means of an instrument, the pilot of the aircraft is afforded a continuous indication of the direction in which the target drifts off the vertical wire. He can then direct his plane accordingly. Finally, the matter of cross trail is settled easily by tilting the telescope crosswise through a small angle sufficient to intercept the correct amount of cross trail on the ground.

Low Level Bombing

RANGE ANGLE AIMING.—A bombsight, designed to operate at altitudes below 5,000 feet, requires extreme accuracy in measurement of the input variables when the range angle method is used for determination of the bomb release point. This is especially pronounced when the altitude falls below 1,000 feet, as it does in the case of depth charging of submarines from low flying aircraft. At such low altitudes the trail value is negligible by comparison to other factors. Therefore, unless the altitude and closing speed can be held very closely to preassigned values, errors in these quantities will produce large range errors on the ground. To overcome these difficulties, the angular rate method is used to determine bomb release.

THE ANGULAR RATE METHOD.—During the early stages of a low level approach, when the target is at a considerable distance from the aircraft, the angle of depression changes very slowly so that the angular velocity of the target at the observer's eye is low. (See fig. 3–15.) As the aircraft nears the target, the angular velocity increases, finally becoming a maximum as the aircraft passes vertically over the target.

At some point during this bombing run, the target was in an appropriate position for a bomb to be released. At that point it had an ANGULAR VELOCITY that could be calculated in terms of the HEIGHT and GROUNDSPEED of the aircraft. If this calculated angular velocity is set up on an appropriate bombsight in such a manner that we can detect when the target has an equal angular velocity, then we have an indication at the instant, during the tracking run, when a bomb should be released to strike the target.

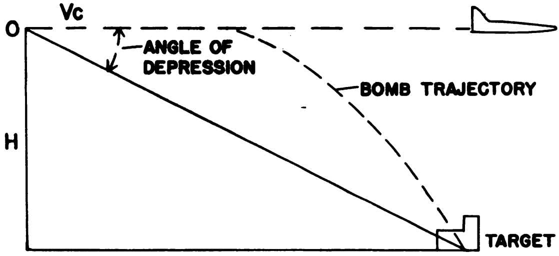


Figure 3–15.—Low level bombing.

One of the first pieces of equipment using the angular rate principle involved a rotating, internally illuminated drum upon which was cut a fine pitch spiral. A portion of the drum, when viewed through an optical system, revealed to the bombardier a set of horizontal illuminated lines moving downward at a uniform velocity. The drum was driven about a vertical axis by a constant speed motor through a variable speed gear which allowed for variation in the rate of rotation of the drum. The variable speed gear in turn was connected by a flexible drive to a computer whose inputs were groundspeed and altitude. Proper functioning of the computer then produced a drum rotation rate so that the illuminated horizontal lines moved at an angular rate equal to that of the target at the correct moment of bomb release.

When the target first appeared to the bombardier on the upper end of the illuminated "ladder," it was moving downward more slowly than the horizontal lines which appeared to be overtaking the target. The difference in rates of the target and the lines became less and less, until at one instant the target and lines appeared stationary together. This was the correct moment of bomb release. After this instant, the target had a greater angular velocity than the lines, and appeared to overtake them.

A more recent type of equipment using the angular rate principle employs a gyroscope to measure the angular rate of the target. Sights of this type are rotatable about horizontal and vertical axes so that the bombardier, after first aligning the sight properly in azimuth, tracks the target by rotating the sight vertically at a rate to keep an illuminated reticle on the target. Rotation of the sight precesses the gyroscope whose precession in turn is opposed by a spring. The tension of the spring is preadjusted for the bombing course to be run. It is set so that it will balance the torque of the gyroscope when the gyroscope is precessed at the angular rate that is critical for that course. One of the principal advantages of the modern angular rate bombsight is that it removes the undesirable feature in the early types of having the pilot judge when zero relative rate between the moving lines and target is achieved.

Dive Bombing

Dive bombing is accomplished by flying along a dive bomb path as illustrated in figure 3–16. This path provides the proper aiming allowance at the release point to obtain a hit. By following a path as shown in figure 3–16, the aircraft is directed at point *A* beyond the target *T*, so that when the bomb is released at point *R* it will not fall short due to gravity. Hence at release, the sight line to the target and line of flight are at an angle to each other.

In the development of dive and glide bombing, as the altitude for beginning the pullout increased, the need for equipment to indicate the correct release point increased. The big problem in dive bombing has always been to try to determine the proper point to head the airplane. For any

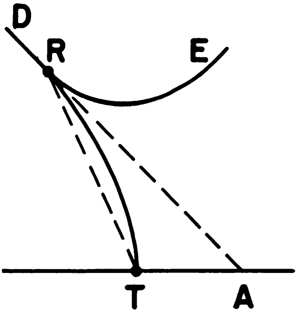


Figure 3–16.—Dive bombing.

given plane speed, plane load, and dive angle, the amount of offset that must be allowed above or below the boresight line of the aircraft, so that the plane will fly a straight path to the target, can readily be determined. However, the bomb, when released, will always fall short by an amount which is mathematically a function of height and the ballistics of the bomb. Accordingly, the problem has been cared for by trying to dive the plane at a constant speed with a known load and dive angle, and using the sight to aim the plane at the target in accordance with the two offset corrections listed.

A sight has been constructed to operate on the angular rate principle, but after numerous flight tests, was finally rejected for the following reasons. First, it was found too difficult for the pilot to maneuver his plane in the diving attitude so as to achieve synchronization. Actually, the pilot had to fly a curved path through space and at the same time try to recognize a condition of no drift between the cross wires and the target. Second, when once in a dive, the pilot found it almost impossible to make a deflection drift correction since there is no way to make an airplane move sideways in space. The fact that range and deflection drift change continuously creates a problem virtually impossible for the dive bombing pilot to solve.

The difficulties just mentioned could be reduced perhaps by a new equipment, but could hardly be avoided altogether, since they are inherent in the dive bombing method. The method of toss bombing, considered in the next section, eliminates these difficulties for the pilot by permitting him to dive straight at the target.

Toss Bombing

In toss bombing, the airplane is flown initially along a collision course, a straight-line path containing the target. If the bomb was released en route, gravity would cause it to fall short. To overcome this effect, the pilot pulls out of his straight-line dive and releases the bomb at a precalculated point along this pullout curve.

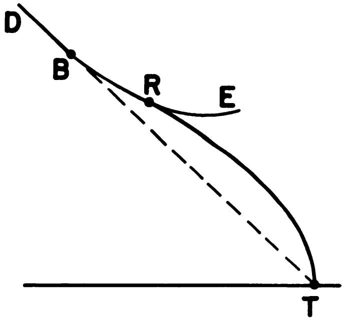


Figure 3–17.—Toss bombing.

Toss bombing is accomplished by flying along a toss bomb path as illustrated in figure 3–17. This attack varies from dive bombing in that the flight path is directed at the target for a short period, at the end of which a pull-up is executed (point *B*). The bomb is released at a suitable point *R* along the pull-up curve.

To relieve the pilot of the responsibility of computing and trying to maintain all the necessary conditions, several bomb directors have been devised to aid the pilot in solving the bombing problem. In toss bombing, release does not occur until after pullout has imparted to the missile a velocity whose horizontal component is the correct one for the trajectory of the bomb. The angle of attack and the dive angle are measured by a gyro which establishes a line reference. Thus, the pilot has only to control speed, or average speed, and aim the plane for the proper allowance on his sight reticle. This allowance can be set in the sight so that the pilot can place his pipper directly on the target.

The use of a gyro and the possibility of its tumbling during violent maneuvers limits the tactical application of an airplane so equipped. Accordingly, a bomb director that eliminates the need for gyros was next developed. An additional improvement is that this director can also be used for higher altitudes and can release a variety of missiles having different ballistics during the same pass.

Loft Bombing

Loft bombing is a means of making a low altitude, level approach to a target with a maneuver which keeps the aircraft well away from the target. The attack path, as shown in figure 3–18, requires that the aircraft pass over a landmark in direct line to the target at a specified altitude. After the elapse of a preset time interval, a pull-up is executed at point *B*. The pull-up point is determined by the characteristics of the aircraft and must be sufficient so that the aircraft will pass through the release point *R* at the desired climb angle.

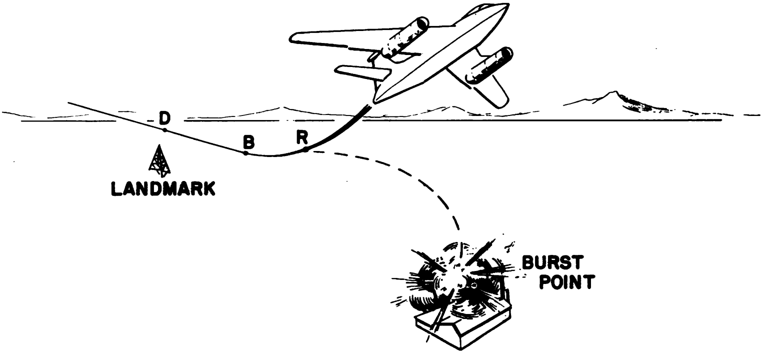


Figure 3–18.—Loft bombing.

In contrast to the toss bombing maneuver, in which no preflight planning is necessary except that required for determining the line of flight with respect to the armament datum line, the loft bomb attack must be planned in detail and executed according to plan.

The release point (fig. 3–18) is determined by the speed of the aircraft at the instant of release and the desired horizontal range. In the attack the pilot flies so that he will pass over the landmark in a direct line to the target. The approach is made in level flight at a prescribed altitude. At the instant he passes the landmark, the pilot presses a switch and keeps it depressed until actual bomb release occurs.

At the end of the preset time interval, or in other words, at the pull-up point, the pilot's indicator is energized, signaling the pilot that he should commence pull-up. The pull-up should be as rapid as possible. Bomb release occurs automatically when the product of pull-up acceleration and pull-up time reaches a preset value. After the bomb has been released the pilot may make any desired maneuver to leave the target area.

QUIZ

1. The most common means of acquisition of a target by airborne fire control equipment is
    a. guns
    b. rockets
    c. visual contact
    d. radar
2. Stadiometric ranging is determined by means of
    a. triangulation
    b. vector analysis
    c. integration
    d. resolver networks
3. In present day lead-computing sights, which of the following quantities is a fixed hand input?
    a. Target range
    b. Wingspan of the target
    c. Lead angle
    d. Diameter of the reticle image pattern
4. By keeping the reticle image on the aim point, the pilot automatically flies a
    a. collision course
    b. parallel course
    c. pursuit course
    d. diversion course
5. If the pursuit course is carried through, the fighter will eventually be in a
    a. tail chase (attack)
    b. head-on attack
    c. broadside attack
    d. midbeam attack

6. A collision course is best used by a fighter plane when
   a. a constant firing of projectiles is most effective
   b. a single salvo of projectiles is most effective
   c. the weapons are within range of the target and are bearing on it for several seconds
   d. employing multiple projectiles, such as machinegun fire

7. A plane firing a guided missile would fly a
   a. diversion course
   b. deflection course
   c. pursuit course
   d. collision course

8. Velocity is a
   a. scalar quantity
   b. angular quantity
   c. vector quantity
   d. nonlinear quantity

9. Speed is a
   a. scalar quantity
   b. angular quantity
   c. vector quantity
   d. nonlinear quantity

10. The magnitude of velocity is found by
   a. dividing the time by the distance
   b. dividing the distance by the time
   c. multiplying distance by time
   d. multiplying the rate of speed by the distance

11. An increase in velocity with respect to time is known as
   a. linear velocity
   b. relative velocity
   c. acceleration
   d. speed

12. In each revolution there is/are
   a. 1 pi radian
   b. 2 pi radians
   c. 3 pi radians
   d. 4 pi radians

13. Angular velocity is represented by the symbol
   a. μ (mu)
   b. α (alpha)
   c. θ (theta)
   d. ω (omega)

14. Acceleration of a free falling body is at a rate of ____________ feet per second per second.
    a. 16
    b. 23
    c. 32
    d. 64

15. The angle τ (tau), measured from the gun platform bow to the gun target line, is called
    a. angle-on the target
    b. angle difference between targets
    c. angle-off of the target
    d. angle to the target

16. The angle at which one must aim the gun, in the stationary gun and stationary target situation, is determined by
    a. wind and gravity
    b. gravity and kinematic lead
    c. wind, gravity, and future target position
    d. gravity and time of flight of the projectile

17. In the case of aircraft strafing, ____________ leads are required.
    a. positive
    b. negative
    c. no
    d. both positive and negative

18. Assuming the firing aircraft to be still and target moving, that the relative angular velocity is 5 degrees, and that the time of flight of the bullet to predicted target position is 2½ seconds, the necessary lead angle at that instant will be
    a. 5 degrees
    b. 12½ degrees
    c. 10 degrees
    d. 2½ degrees

19. Angular rate is divided into
    a. azimuth angular velocity and range velocity
    b. azimuth rate and range rate
    c. azimuth angular velocity and elevation angular velocity
    d. range velocity and elevation angular velocity

20. In lead-computing sights, there is/are ____________ gyroscope(s).
    a. 1
    b. 2
    c. 3
    d. no

21. In almost all optical fire control systems, gyroscopes are used to determine the
    a. azimuth portions of angular velocity
    b. elevation portions of angular velocity
    c. azimuth and elevation portions of angular velocity
    d. range portions of angular velocity

22. In the radar director system, measurement of angular velocity is accomplished by
    a. two rate gyros in the computer assembly
    b. one rate gyro in the computer
    c. one rate gyro in the antenna assembly
    d. two rate gyros in the antenna assembly

23. The distance between the fighter and where the target will be when the projectile strikes the target is called
    a. present range
    b. future range
    c. stadiametric range
    d. angular range

24. Target future position is denoted by the symbol
    a. T_f
    b. t_f
    c. t_r
    d. r_f

25. Kinematic lead angles in respect to ballistics lead angles are generally
    a. smaller
    b. larger
    c. the same
    d. constant

26. At what altitude is level bombing considered low level bombing?
    a. 5,000 feet
    b. 10,000 feet
    c. 15,000 feet
    d. 25,000 feet

27. The symbol for the range angle in the bombing problem is
    a. ω (omega)
    b. θ (theta)
    c. ϕ (phi)
    d. R

28. Air resistance affects the path of a falling bomb by
   a. increasing the vertical velocity of the bomb and diminishing the horizontal velocity of the bomb
   b. increasing the vertical velocity and increasing the horizontal velocity of the bomb
   c. decreasing the time of fall and increasing the horizontal velocity of the bomb
   d. decreasing the vertical velocity and diminishing the horizontal velocity of the bomb

29. In the bombing problem, the drift angle is known as the angle
   a. ϕ (phi)
   b. θ (theta)
   c. ω (omega)
   d. μ (mu)

CHAPTER 4

AIRCRAFT NONCOMPUTING SIGHTS

The purpose of this chapter is to study certain optical principles and the sights and sight systems whose operation is based on these optical principles. The basic ideas will be presented first. These will be followed by a discussion of the development of the various sighting methods. In conclusion will be a discussion of the Navy's aircraft noncomputing sights.

OPTICS

Consider for a moment the diagram in figure 4–1 and the following associated statement: "As the light rays pass through the lens system, they are magnified and COLLIMATED until all the rays of light coming through the optical system from any one point on the reticle are parallel with each other." While the ideas presented in this statement are not necessarily difficult or complex, they do not fall in the category of general knowledge. Does it have real meaning for you?

The preceding diagram and quoted statement are representative of the description used in pamphlets and manuals for aviation fire control equipment. As you see, they presuppose a knowledge of basic optics. After a study of this section, the statement and the diagram should have more meaning for you.

Nature of Light

If you light a candle in a dark room, not only is the flame itself visible but also other objects in the room are made visible by the presence of the flame. Therefore, the flame

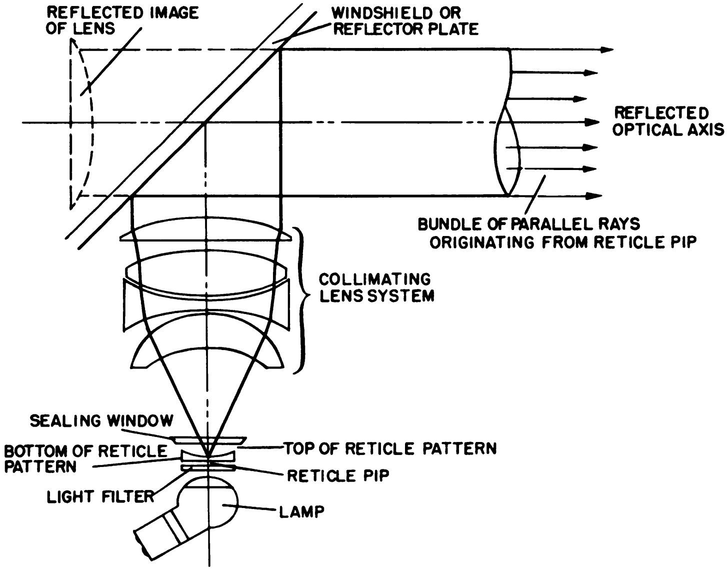


Figure 4–1.—Optical diagram of illuminated sight system.

must be the source of our seeing or, in other words, the source of some physical action called light. What is the nature of this physical agency called light?

The answer to this query has been the object of observation and conjecture since early times. It is interesting to note that the ancient Greeks considered the eye as the source of light. This first theory that vision was due to do something originating in the eye illuminating the seen object was disproved by the question: Why cannot we see in the dark? Years later this idea was followed by the corpuscular theory developed by Sir Isaac Newton. He believed that light is a stream of particles or corpuscles leaving the source and traveling in a straight line unless turned by reflection or refraction.

WAVE THEORY.—The corpuscular belief, in turn, gave way to the wave theory developed by Huygens and Young. They considered light energy as waves traveling through space in much the same way water waves ride the ocean, or sound waves travel through air. In 1862 Maxwell further advanced this theory by showing that the wave hypothesis satisfied more conditions when it was assumed that a light wave consisted of a varying electric and magnetic field.

QUANTUM THEORY.—But the wave theory did not answer all the questions, especially when the physicists began to investigate the light-producing objects. They found that light is emitted in minute quantities of energy called QUANTA, which never vary in size for a given frequency. This is called the QUANTUM THEORY, and was later proved mathematically by the famous physicist, Albert Einstein. So it appears that light can be though of not only as radiated energy in the form of waves, but also as minute packs of energy streaming outward from their source.

Neither theory is complete in itself, for neither will satisfy all the facts known about the nature of light. However, many very convincing experiments have been used to support both ideas. When physicists are studying or explaining the source of light or the effect upon matter when it stops, they use the quantum theory. If the study concerns how light travels, the wave theory is utilized. Because this course deals with the travel of light in optical instruments, the wave theory will be used.

Behavior of Light

Recognizing that there are inconsistencies in the theories of the nature of light, our main purpose is not so much to determine what light is but to describe as simply as possible how light behaves.

In considering the behavior of light, the first observation to be made is that light travels in a straight line. All ordinary actions resulting from seeing are based on this straight-line propagation of light. There are devices and means for causing light to go around corners, but by itself light travels in a straight line. These turning devices will be discussed later.

Anything that you see is a source of light. A source which furnishes its own light is said to be LUMINOUS. Examples of this source would be the sun, a flashlight, or a candle. If a source actually reflects light from another source, it is NONLUMINOUS. Examples would include the moon, a wall, and the pages of this book. Of course, if the original source of light is removed, the nonluminous source ceases to give off light. Needless to say, you cannot read this page in a darkened room. It is interesting to note that most sources of light also produce a result that does not affect the sense of sight; namely, ultraviolet and infrared radiation.

RADIATION OF LIGHT.—The radiation of light from a source has often been compared to the ripple (or disturbance) caused by the dropping of a stone in a pool of water. Although the analogy has limitations, it serves to illustrate the original propagation of light waves from a source. To get a truer picture of the physical action, replace the falling stone with a source of continuous vibrations—a luminous light source. Now instead of projecting the waves on a plane surface such as water, project them in three-dimensional space. Figure 4–2 illustrates the propagation of light waves from a luminous source. Remember that the waves are projected in three dimensions and not in two dimensions such as the surface of this page.

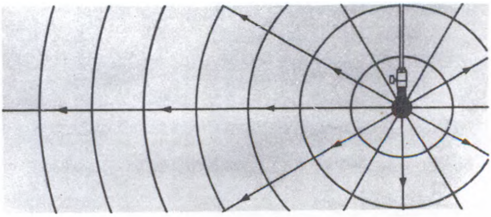


Figure 4–2.—A light source propagates waves in all directions.

LIGHT RAYS.—In studying light in connection with optical equipment, it is usually more convenient to consider single rays of light and trace their paths. The straight lines along which light travels from a point source in some uniform medium, such as water or air, are called RAYS. (See fig. 4–3.)

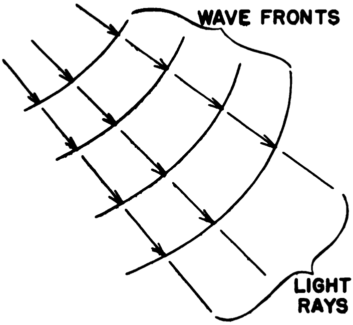


Figure 4–3.—A ray shows the direction the waves are traveling.

Of course a single ray of light does not exist. If a diagram of an optical instrument is made showing light passing through it in the form of waves, the result, in all probability, would be more confusing than helpful. The use of rays will simplify considerably the study of the equipment. In some pamphlets on fire control equipment, light is shown as a beam as in (A) of figure 4–4; but it usually is clearer to show light as two or three sample rays as in (B) of the figure. Notice that the rays are shown as white lines on a

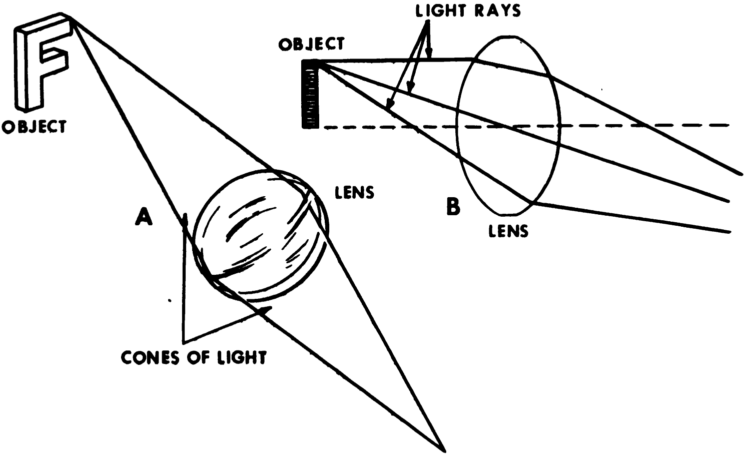


Figure 4–4.—Symbols and types of illustrations used to show light paths.

dark background, and that arrowheads indicate the direction of the rays of light.

VELOCITY OF LIGHT.—Common observation shows us that the speed of light is much greater than the speed of sound. For a long time people thought that light traveled instantaneously, at infinite speed, because they had no way to measure it. Through the work of Michelson and other scientists, the velocity of light has been established as one of the most accurately known physical constants. In determining the actual speed of light, the medium of travel is very important. It has been found that light travels slower in matter than it does in free space. In air, or in a vacuum, light travels at about the same speed or approximately 186,000 miles per second. The fact that light travels slower in a denser material, such as glass, permits a glass lens to bend rays of light to a focus.

TYPES OF MEDIUMS.—From your observation of the physical world, you are aware that all matter will not serve as a medium of propagation for light. Some materials will readily pass light, while others will not permit the passage of light. For convenience, all things are divided into three classes, depending on how light is affected when it falls on them. First, if all the light that falls on an object is reflected or absorbed, it is considered to be OPAQUE. No light goes through. Second, if some of the light is reflected, some absorbed, and some goes through, the object is called TRANSLUCENT. The third category is TRANSPARENT objects which reflect a little light, absorb a little, but let most of the light pass through.

Reflection of Light

In the discussion so far, the reflection of light has been mentioned several times. Realizing that the concept itself is well known, the purpose of this section is to investigate some of the ramifications of the idea. Whenever light strikes the boundary between two mediums, such as air–water, air–glass, glass–metal, some of the light is turned back or reflected. The light that is not reflected is transmitted through or absorbed in the material. A highly polished surface reflects more light than a rough surface. A rough surface, such as unglazed paper, reflects the light more or less in all directions, thereby appearing dull. If the light strikes a carefully polished surface, such as a mirror, the light enters the eye as though coming directly from a distant object instead of from the reflecting surface. This is called REGULAR REFLECTION. A good example of the use of mirrors is an aircraft sight system.

MIRRORS.—The function of a mirror is shown in figure 4–5. Although the eye actually sees the reflected image of the object, it apparently sees a virtual image because the object appears to be behind the mirror. Furthermore, the image is reverted or turned from side to side. In general, an image in a plane mirror is the same size as its object, and appears as far directly behind the mirror as the object is in front. Notice also that the rays leaving the object are called the INCIDENT RAYS, while the rays leaving the mirror are called the REFLECTED RAYS.

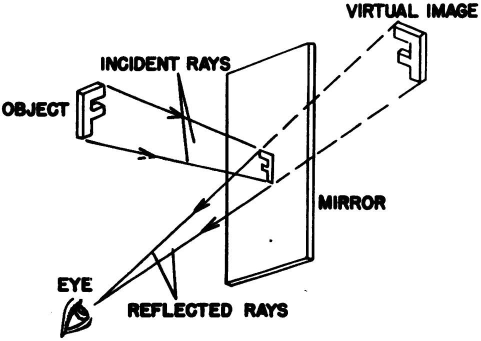


Figure 4–5.—The mirror forms a virtual image.

There is a definite relationship between the angles of these rays and the normal. The normal is the plane perpendicular, or at a right angle, to the reflecting surface. This relationship is given by the law which states that THE ANGLE OF REFLECTION IS EQUAL TO THE ANGLE OF INCIDENCE. (See fig. 4–6.)

Because all mirrors are not plane surfaces, the next con-

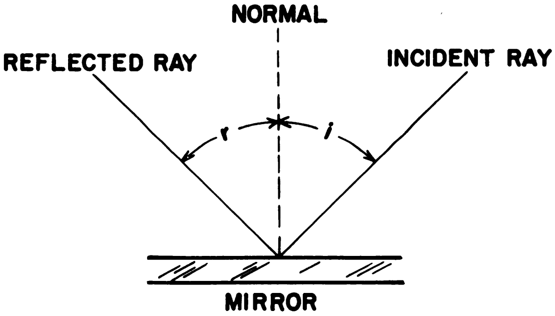


Figure 4–6.—The angle of reflection is equal to the angle of incidence.

siderations will concern curved mirrors which are usually a portion of the surface of a sphere. If the mirror is a portion of the outer surface, it is called CONVEX. If it is a portion of the inner surface, it is called a CONCAVE mirror.

When light rays parallel to the principal axis strike a convex mirror, the reflected rays diverge or spread out. If the light rays striking the mirror are other than parallel, then the rays of light reflected from a convex mirror are more divergent than the incident rays. The law of the angle of reflection being equal to the angle of incidence still applies. An example of the reflection of light rays from a convex mirror is shown in figure 4–7. The image of any object in front of a convex mirror appears to be behind the mirror, and seems to be erect but smaller than the object.

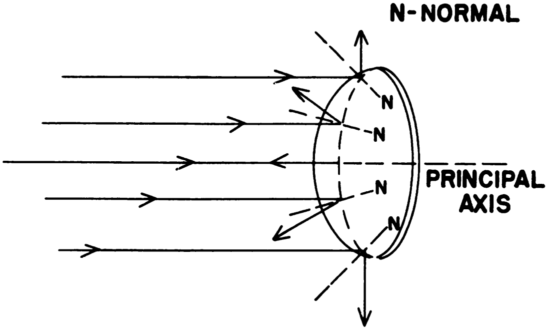


Figure 4–7.—Reflection of parallel rays form a convex mirror.

When light rays parallel to the principal axis strike a concave mirror, the reflected rays converge or come together. If the light rays striking the mirror are other than parallel, then the light rays reflected from the mirror are more convergent than the incident rays. As shown by figure 4–8, when parallel rays are reflected from a concave mirror, they converge to a point, cross, and diverge again. The point where the rays cross is the principal focal point of the mirror.

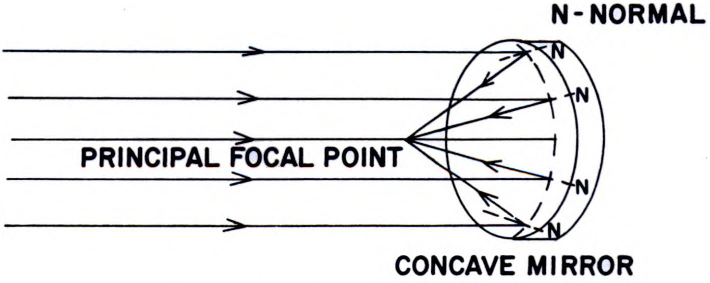


Figure 4–8.—Reflection of parallel rays from a concave mirror.

Actually all the rays do not cross at this point but the majority of them do. If, instead of a spherical, a parabolic surface is used, the result is that all rays parallel to the axis are reflected accurately through the focal point. Conversely, light radiating from the focal point is reflected as parallel rays. A good example of this effect is the intense beams reflected from searchlights.

Refraction of Light

It is a matter of common observation that when a stick stands obliquely in water, it appears to be broken at the surface of the water in such a way that the part under water seems to be bent upward. Consider also how goldfish appear enlarged and distorted when viewed through the curved sides of a bowl. These are examples of the phenomena called the REFRACTION OF LIGHT. Actually, refraction is the changing of direction or bending of light rays as the light travels from one medium to another.

For an understanding of the refraction of light, imagine a beam of light (fig. 4–9) passing in slow motion through a sheet of glass. Both plane surfaces of this glass plate are parallel, and air is in contact with both surfaces. Although both glass and air are transparent, the glass is denser than air, and therefore causes light to slow down when it passes from the air into the glass. This slowing down of light causes the beam to bend whenever the wave fronts strike the glass at an angle.

If the beam strikes the glass directly at right angles (along the normal), the light is not bent or refracted. Its speed decreases upon encountering the denser medium, but because the entire wave front strikes the glass at the same instant, its path is not deviated. Upon reaching the lower glass surface, the beam enters the lighter air medium and again resumes its faster speed.

Now, if this beam strikes the glass at an angle with the normal, one edge of the wave front strikes the glass first. The edges of the wave fronts arriving at the glass first are slowed down upon entering the denser medium and the beam is deviated or refracted toward the normal (fig. 4–9).

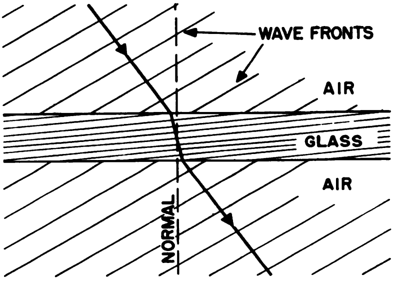


Figure 4–9.—Path of wave fronts through a sheet of glass.

Upon leaving the other surface of the glass plate, the light is again refracted, but this time away from the normal. Of course, the wave-front edge which enters the glass first traverses the glass first, so upon leaving the denser medium the edges of the wave fronts that leave the glass first are speeded up, thereby causing the beam to turn away from the normal.

If the faces of the denser medium are parallel, as in figure 4-9, the bending at the two faces is the same. Thus, the angle of incidence is equal to the angle the emergent ray makes with the normal. And since the surfaces are parallel, the incident and emergent rays are parallel.

Refraction of light can be summarized by the following: When light enters a denser substance obliquely, it is bent toward the normal, and when light obliquely enters a substance of lesser density, it is bent away from the normal. The amount of bending at the boundaries of the mediums depends upon the ANGLE OF INCIDENCE, and upon the RELATIVE DENSITIES of the mediums under consideration.

It should now be apparent that the direction of light waves can be controlled by constructing devices of the appropriate medium and with the correct angle. Such devices are lenses. The refraction of light is basic to the performance of lenses.

MIRAGE.—Another interesting example of the refraction of light is a mirage. On a warm, still day there sometimes exists a layer of hot expanded air next to the ground. This hot air is slightly less dense than the cold air above it. Light waves entering obliquely from a distant object have their rays turned upward and give the appearance of the distant objects being reflected from a lake. The appearance of water on a highway on a hot day is another example of a mirage.

CRITICAL ANGLE.—Consider the passage of light from water to air. It has been observed that when light is passed from a denser material to a less dense substance, a portion of the light may be reflected rather than refracted. The factor that determines if the light will be completely reflected is the angle formed between the light rays and the normal. The CRITICAL ANGLE is the angle in the denser medium which must not be exceeded if the ray is to pass out. Assuming that one medium is air, the critical angle is dependent upon the other denser material, and therefore related to the angle of refraction. As you recall, the angle of refraction is determined by the angle of incidence and the relative densities of the mediums under consideration. As either density or the angle of incidence increases, the angle of refraction becomes proportionally larger. Eventually a point is reached where the light rays are refracted at such an angle that they travel along the surface of the denser medium.

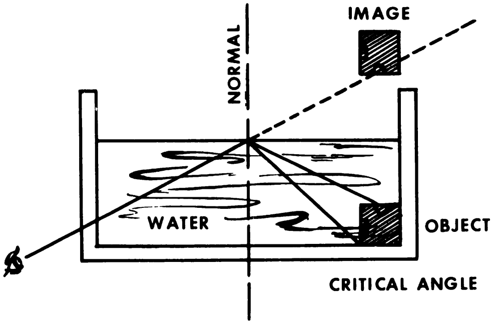


Figure 4–10.—Total reflection by exceeding the critical angle.

Any angle greater than the critical angle also results in total reflection of the light rays. Figure 4–10 shows the total internal reflection of the rays by the surface of the water. Obviously the critical angle has been exceeded and the result is total reflection. A practical application of the critical angle is the design of prisms used in aviation fire control equipment.

Prisms.—It is often necessary to change the direction of the light path. This change may be accomplished by the use of mirrors, but prisms will do it much more satisfactorily. The method employed in using prisms is to construct them with an angle greater than the critical angle. The result of such construction is that the reflecting surface will appear silvered.

Figure 4–11 shows a prism with two sides perpendicular (at right angles) and the third side at 45 degrees with the other sides. It resembles a right triangle laid over on its side. Trace the light rays leaving the object and entering the prism. There will be no refraction as the rays are enter-

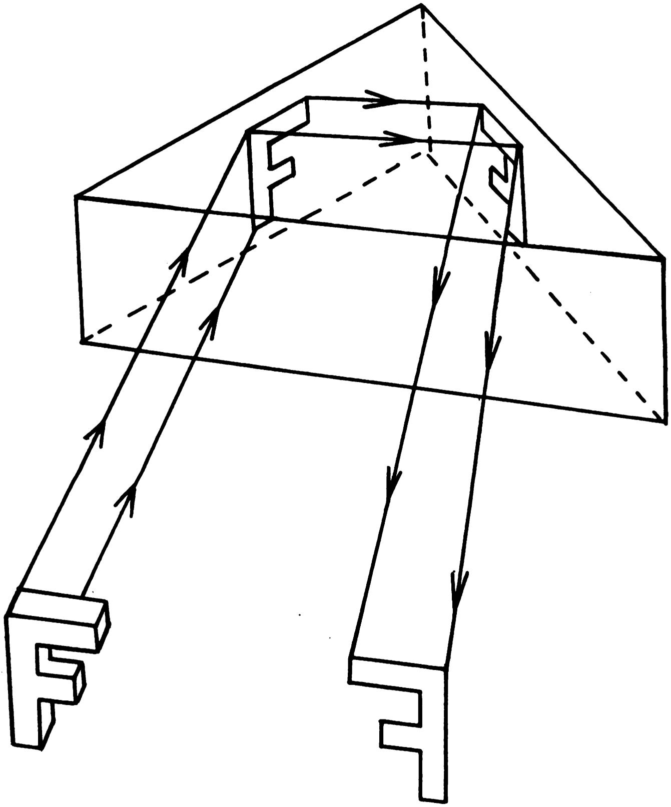


Figure 4—11.—Total internal reflection in the right angle prism.

ing perpendicular to the surface. The rays then will continue until reaching the next surface, which is on a plane 45 degrees removed from the direction of travel of the light rays. Considering the prism medium to have a critical angle of less than 45 degrees, the rays will be totally reflected.

After striking the first back surface and being reflected, the rays will continue to the second back surface where the reflection will be repeated. Notice the emergent ray is parallel to the incident ray. The image is reverted, but is normal or upright. This prism can also be used to reflect at an angle of 90 degrees by orienting the prism so that the incident ray enters one of the sides, is reflected off the back, and emerged from the other side.

Another important use of the prism is the bending of light rays by refraction. When light rays strike the internal boundary surfaces of a prism at angles smaller than the critical angle, they pass on through and are refracted. As shown in figure 4–12, the incident ray is bent toward the normal upon entering the prism, and away from the normal upon leaving the rear face according to the rule of refraction.

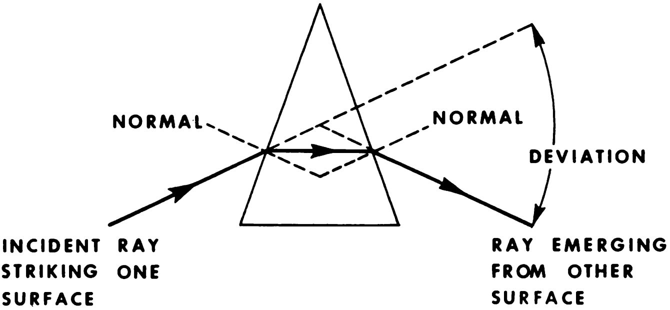

NORMAL
NORMAL
DEVIATION
INCIDENT RAY STRIKING ONE SURFACE
RAY EMERGING FROM OTHER SURFACE

Figure 4–12.—Refraction in a prism.

Notice that each bend is in the same direction. The angle between the incident ray and emergent ray is called the DEVIATION OF THE PRISM.

Lenses

One of the most important applications of refraction is in the construction of a lens. In the majority of fire control equipment you will encounter lenses in one form or another. A lens is a piece of glass, or other transparent substance, used in optical instruments for forming an image by changing the direction of rays of light. The two opposite regular surfaces of a lens are either both curved or one curved and the other plane. Usually the curved surfaces are spherical. Generally, lenses are one of the six types shown in figure 4–13.

Lenses are divided into two classes—CONVERGENT and DIVERGENT lenses. A convergent lens is often called a POSITIVE lens, while a divergent lens is a NEGATIVE lens. Notice that

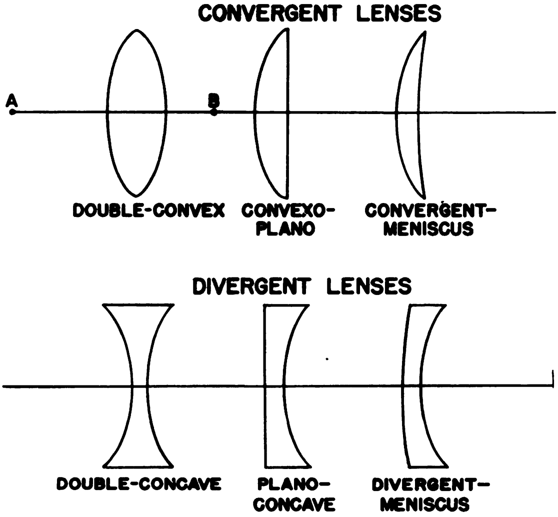


Figure 4–13.—Types of lenses.

the convergent lenses in figure 4–13 are thinner at the edges while the divergent lenses are thicker at the edges. When a light ray passes through a lens, it is bent toward the thicker part of the lens, except when it passes along the principal axis (line *A* to *B*, fig. 4–13). As would be expected then, the light rays are bent in opposite directions in these two classes of lenses.

Consider light passing through a double-convex lens. Because lenses are made of optically dense material, the velocity of light through a lens will be slower than through air. In any thin-edged (convergent) lens the light passing through the center will be retarded more than the light passing through the edges. This results in the center section of the wave being held back and the wave, after passing through the lens, converges to what is called the FOCAL POINT. Once again using the ray concept (rays indicate the direction of wave travel), this convergence is shown in figure 4–14.

Notice that the parallel rays converge to the focal point and that the focal length is the distance from the center of the lens to the focal point. Although the focal point is de-

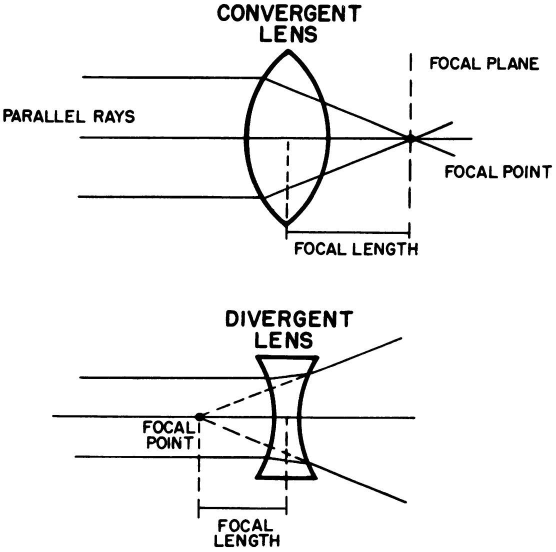


Figure 4–14.—Convergent and divergent lenses.

fined as a fixed point for a given lens, the light rays will not always converge at this point. If the light rays emitted from an object are not parallel, the lens will converge then to a point beyond or ahead of the focal point. Rays coming from points on a distant object, when passed through a convergent lens, will converge at corresponding points on a plane drawn through the focal point. This is called the FOCAL PLANE. If a screen is placed in this position, a real image of the object will be reproduced.

Since an incident ray and its corresponding refracted ray are reversible, it follows that a source of light placed at the point of focus would project its rays through the lens in such a way that the rays would be parallel. Remember that if all rays from a point are parallel, the point will appear to be at an infinite distance. The use of parallel rays in this manner will be found in aircraft sight systems.

If rays of light strike a divergent lens (lower section of fig. 4–14), the rays are refracted so as to diverge upon leaving the lens. The point of principal focus of the divergent lens is located where the emergent rays from a distant object (parallel rays) would intersect if they were extended backward as imaginary lines toward the side of the lens on which the light strikes.

The image of an object, as seen through a divergent lens, always appears to be located somewhere between the focal point and the lens. Therefore, it gives the appearance of being between the object and lens, directly behind the lens, and will be smaller than the object. This image is called a virtual image because it is an optical illusion and cannot be thrown upon a screen.

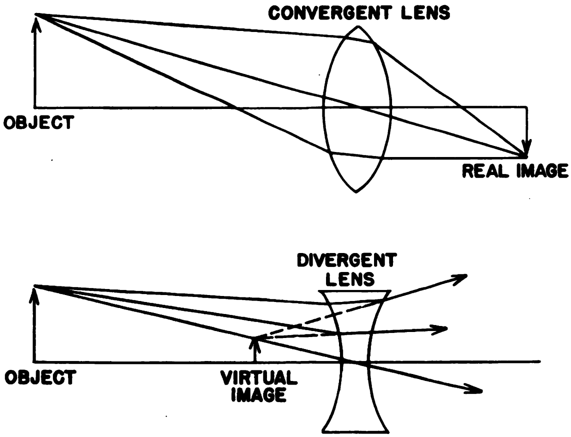


Figure 4–15.—Image formation with convergent and divergent lenses.

The formation of an image by convergent and divergent lenses is shown in figure 4–15. When the object is located outside the focal point of a convergent lens, the lens forms a real, inverted image as indicated. When the object is located outside the focal length of the divergent lens, a virtual normal image is formed which is always smaller than the object and located between the focal point and lens.

Magnification.—The ratio of the size of the image to the size of the object is called magnification. It can be shown by similar triangles that the following relationship describes magnification:

$$\frac{\text{Size of image}}{\text{Size of object}}=\frac{\text{Distance of image from lens}}{\text{Distance of object from lens}}$$

Notice that to obtain a magnification of TWO, the distance of the image will have to be TWICE the distance of the object from a lens. This leads to the conclusion that a single lens is not practical for viewing objects at a long distance. If a convergent lens is used to observe a far distant object, the light rays, which are parallel, will converge on the focal plane a short distance behind the lens. The result will be a very small size image.

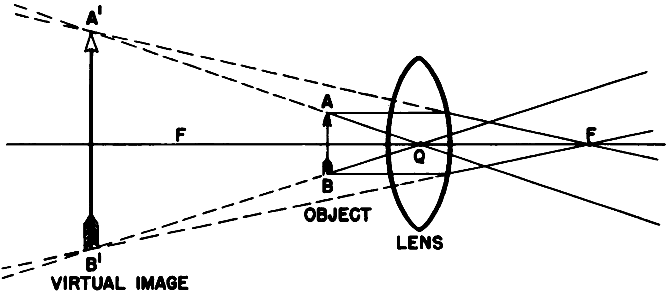


Figure 4–16.—Enlarged, virtual image formed by convergent lens.

Convergent lens are used, however, as magnifying glass. From your past experience it should be easily recalled that to obtain an enlarged image of an object, it is necessary to get the lens close to the object. The distance of the lens from the object must be nearly equal to the focal length of the lens. If the distance is greater than the focal length, the image is real and enlarged. If the distance is less than the focal length, an enlarged, erect, virtual image is obtained. (See fig. 4–16.)

COMPOUND LENS.—A compound lens is a combination of simple lenses cemented together. It is necessary to use a compound lens to offset an effect termed SPHERICAL ABERRATION. Briefly, spherical aberration is caused by the light rays which strike the outer portions of a lens being refracted more than the rays which fall on the central portion of the lens, and therefore come to a focus nearer the lens. A compound lens cures this effect by using divergent and convergent lenses which have opposite spherical aberration. Thus, when a compound lens is the right combination, it cancels the aberration.

THE HUMAN EYE.—Considered as an optical device, the eye is quite simple. It consists essentially of a lens system, a variable diaphragm called the iris, and a light sensitive section called the retina. It is upon this light sensitive section, made up of a multitude of tiny light sensitive cells, that images of external objects are projected.

The refracting mechanism consists primarily of a crystalline lens, cornea, and aqueous humor. Together, these form a compound lens. The crystalline lens is an adjustable double-convex-lens suspended by the ciliary body which encircles it as shown in figure 4–17. The curvature of the lens surface is controlled by the ciliary muscles. Control over the surface curvature results in control of the focal length or refractive power.

After passing through this lens system, the light falls upon the retina. The most sensitive spot of the retina is called the fovea centralis. Each of the light sensitive cells is connected to the brain by a nerve. Since the eye effectively refracts like a simple lens, it follows that the real image of an external object must be inverted on the retina. Needless to say, we experience no such inversion because we have learned to associate an inverted image with an erect object.

The sclera, which is the tough, flexible, white portion of the eye normally seen, forms the outer coat. In front, where light enters the eye, the sclera is transparent and bulges out to form the cornea. The cornea and the transparent liquid or aqueous humor behind it are part of the refracting mechanism, and work in conjunction with the crystalline lens.

The middle coat, the choroid, is a deep purple layer made up of veins and blood vessels which supplies nourishment to the eye tissues. The coloring of the choroid forms a dark housing which keeps undesired light out and prevents internal reflection of light rays within the eye.

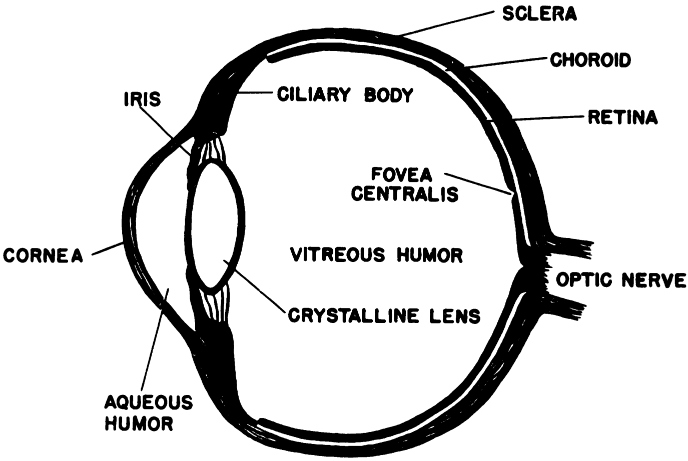


Figure 4—17.—Diagram of the eye.

The iris which is the variable diaphragm of the eye controls the amount of light admitted. It is a colored membrane having in its center a circular aperture called the pupil. The diameter of the pupil is changed by the expansion and contraction of the iris. When the light is bright, the pupil becomes small to prevent damage to the eye. When the light is dim, it enlarges to permit passage of more light.

While both the cornea and the crystalline lens provide refraction, the major converging power of the eye is located on the front surface of the cornea. This explains why we cannot see clearly when swimming under water. The water and the aqueous humor are so similar that there is very little refraction of the light, and the lens cannot focus the light sharply on the retina by itself.

When the eye is in good condition, the focal length of the lens, with the ciliary muscles relaxed, is equal to the distance from the lens to the retina. Parallel rays entering the eye come to a focus on the retina, forming a sharp image.

If you now look at a nearby object, the sharp image will be formed behind the retina. Thus, the light rays falling on the retina will be fuzzy and out of focus. The eye must accommodate this position of the object by having the ciliary muscle cause the lens to thicken and thereby shorten its focal length. This repositions the focal plane in front of the retina, and places the image behind the focal plane, as it should be. Therefore, the image falls sharply on the retina.

As the object comes closer and closer, the ciliary muscle has to squeeze harder and harder. This is why close vision tires the eye. At a distance of about 10 inches, the muscle reaches the limit of its accommodation. The eye cannot focus sharply on objects much closer than this.

When a man is shortsighted (nearsighted) his eyelens has too short a focal length in the relaxed position. That is, the focal plane, with the ciliary muscle relaxed, is in front of the retina. Images of distant objects are formed in this plane, and therefore the image formed on the retina is fuzzy. But at closer distances, the image will get back to the retina and vision will be clear. Concave lenses are used to correct shortsighted eyes.

In the farsighted eye, the lens has too long a focal length and an object at a normal distance is focused behind the retina. Once again this could be caused by the size of the eyeball, the curvature of the cornea, and the focal length of the lens not being properly matched. Convex lenses are used to correct farsighted eyes. This is a very common effect of advancing age.

THE TELESCOPE.—Consider for a moment the conclusion reached under the magnification section: A single lens is not practical for viewing objects at distances. Now if this conclusion is correct, then obviously a telescope must have more than one lens.

When the light rays from a distant object enter the eye, they are essentially parallel to each other and make a very small angle with the eye axis. The rays then converge to a point on the focal plane of the eye. The distance of this point from the axis will depend on the angle the parallel rays make with the eye axis. Since the angle is small, as shown in (A) of figure 4–18, the distance will be small, and the image formed on the retina will be correspondingly small.

Figure 4–18 (B) shows the same distant object being viewed with the aid of a simple telescope composed of two convergent lenses. Now the parallel rays enter the first lens, known as the OBJECTIVE LENS, at the same angle as before. They converge at a point on the focal plane of the objective, forming a real image. Notice that the longer the focal length of the objective lens, the larger the real image. Also observe that the real image is inverted.

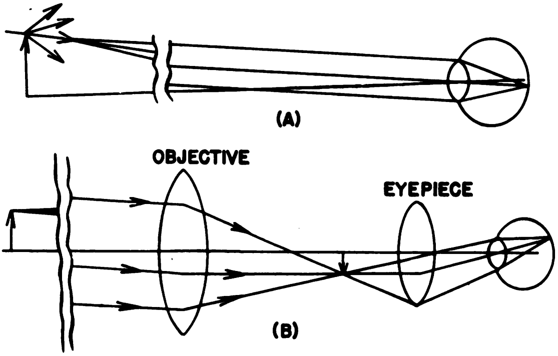


Figure 4–18.—A simple telescope.

A second lens, known as the EYEPIECE OR OCULAR, is so placed that its distance from the real image formed by the objective lens is equal to its focal length. As you know, all rays originating from a point on the focal plane of a lens emerge from the lens as parallel rays. Therefore, the rays emerging from the eyepiece enter the eyelens parallel to each other. But this time the rays make a much larger angle with the optical axis of the eye, and the image formed on the retina is very much larger.

If you looked through this telescope, you would see the virtual image of a real image of the object. Everything that you see would be inverted. To correct for this defect, a lens erecting system is used.

The simplest form of erecting system is an additional converging lens inserted between the objective and the eyepiece. (See fig. 4–19.) The additional lens forms a real image of the real image formed by the objective lens. This second image, being an inversion of the inverted image, is erect and normal. Thus, the eyepiece forms an erect virtual image of this erect real image.

Figure 4–19 shows an erecting lens located twice its focal length from the first real image. The second image being two focal lengths behind the erecting lens is exactly the same size as the image formed by the objective. The net result of installing the erecting lens is that it turns the image over. That is, erection not only inverts the image but also reverts it. The advantages of such a system should be apparent.

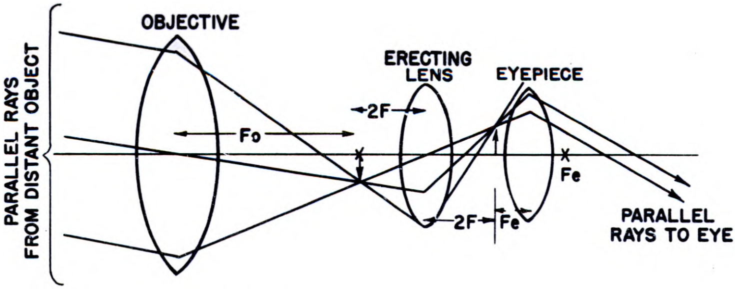


Figure 4–19.—Lens erecting system of a telescope.

It is interesting to note that a microscope operates on the same principles as the telescope. The distinction between the two being the relative differences in size between the first image and the object. If the first image (formed by the objective lens) is larger than the object, it is normally called a microscope. Conversely, if the first image is smaller than the object, it is called a telescope.

Collimating Lenses

One of the requirements of Navy gunsights and fire control equipment is the ability to superimpose a reticle image pattern on the target. To satisfy this requirement, it is necessary that the optics of the system be such that the reticle image appears as if projected to infinity. You will recall that light rays from an object an infinite distance away are parallel. Therefore, if the light rays forming the reticle image are parallel, the image will appear to be projected to infinity. A collimating lens or lens system will bend the light rays until they are parallel.

Essentially, the optical system produces this desired reticle image by placing a light source in line with a reticle. The reticle used in most gunsights consists of an opaque disk containing geometrical openings to produce the desired image patterns. Then the desired light pattern may or may not be through a sequence of mirrors. But eventually the light pattern does reach a collimating system.

As pointed out, the purpose of the collimating system is to render the light rays parallel. Now this may be done by a series of lenses, as in figure 4–1, or it may be accomplished by one lens. Recall how the eyepiece of the telescope made the light rays parallel. After passing through the collimating system, the recticle image is usually interrupted by a reflecting plate, where the image appears to be viewed by the eye. The desired feature has been accomplished.

It is pertinent to point out some other features of the system. Note that the reticle must be located in the focal plane of the system, and therefore the rays from the reticle would be divergent. It is also possible to obtain magnification from a collimating system containing a series of lenses. Finally, since the light rays which come through the optical system from any one point on the reticle are parallel, the image appears to always lie in the same direction from the observer.

Use in Fire Control

A good example of the use of optics in fire control is the optical diagram of the Illuminated Sight Mk 8 shown in figure 4–1. This sight system is used as a primary or standby gunsight in aircraft equipped with fixed, forward firing guns and rockets. Incidently, does the following statement associated with figure 4–1 have any more meaning for you now? "As the light rays pass through the lens system, they are magnified and collimated until all the rays of light coming through the optical system from any one point on the reticle are parallel with each other."

Besides being used in gunsight systems, optics are also found in AIRCRAFT FIRE CONTROL SYSTEMS, ARMAMENT CONTROL SYSTEMS, BOMBSIGHTS, and BOMB DIRECTORS. Some of the equipment functions which were originally optical are now being replaced with electronic means. Examples of this substitution of electronics for optics would be the use of radar for ranging in place of stadiametric ranging and the use of electronically controlled strobes to replace the electromechanical system of determining the rate of change of range.

Of course, there are advantages and disadvantages to both the optical and electronic systems. These will be discussed in the sections of this course covering the different systems. However, a good working knowledge of optics is mandatory of all who hope to successfully study aviation fire control equipment.

SIGHT DEVELOPMENT

During the closing stages of World War I the need for a fast method of aiming or alining guns from aircraft became apparent. The necessity for additional accuracy in controlling missiles became more pronounced as the speed of the aircraft increased and the safe attacking distance became greater. The development of methods of fire control from the "seaman's eye" system to the present computing equipment has kept pace with the development of the aircraft from the "flying Jennys" to the supersonic jets.

As long as there is relative motion between the attacker and target, an allowance for such motion or lead must be taken into consideration. This necessity exists whether the weapons used are guns, rockets, guided missiles, or bombs. Therefore, the solution of the fire control problem is the task assigned the sight or fire control system. Previous to the development of the rocket and the guided missile, the sights were required only for the aiming of guns.

Ring Sights

The .30 Cal. Browning automatic machine guns were the first guns to be mounted on naval aircraft. Because these were the same as the guns in use by the ground forces, the aiming problem was solved by the use of the ring-and-bead sights supplied with the guns. Because of the slow speeds and the short range of the ammunition, it was possible to get hits. Gunners learned through experience where to place the target with respect to the sight in order to obtain these hits.

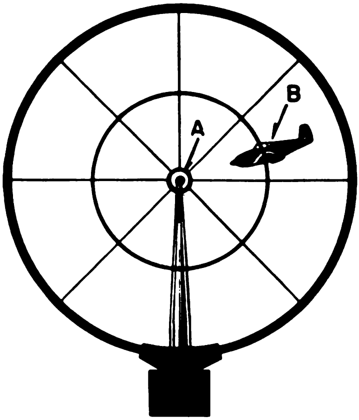


Figure 4–20.—Use of the ring sight.

But, because of the differences between aerial and stationary gunnery, it soon became apparent that improvements were needed. As an aid in determining where the target should appear with respect to the ring, a series of proportional references were incorporated in the sight. This is shown in figure 4–20. The bead on the fore sight is shown at A, and the target plane is at B.

Illuminated Sights

One of the difficulties in the use of the ring sight was that the gunner's eye had to be held in such a position that both the ring and bead were alined with the target. This resulted in a serious restriction of the eye and head movements which, in turn, was very dangerous under combat conditions. To remedy this situation, a method was developed which projected the rings on reticles so that they appeared to the pilot or gunner to be on the target or at infinity. This was first accomplished by use of a telescope sight, but here again vision was definitely limited while the gunner was alining the target. The final answer to this problem was the use of an illuminated reticle projected to infinity. With this equipment the pattern appears to be superimposed on the targets and can be used to determine both lead and range.

The features of an illuminated reticle projected on a reflector plate or windshield and having the appearance of being at infinity were incorporated in Illuminated Sights Mk 8 and Mk 9. The Mk 8 was designed for use in fixed gunnery, while the Mk 9 was intended for free gunnery or turret positions where space is usually restricted.

Elimination of reflector plates.—Until an optically corrected windshield became available for use on combat aircraft, the projected reticle image of the Mk 8 illuminated sight was presented by the use of a reflector plate incorporated in the sight body. Where a fixed reticle image is employed and the aircraft is equipped with an optically corrected bullet-resistant windshield, the image can be projected directly on the windshield, thereby eliminating the reflector plate.

Deletion of sunfilters.—When the Illuminated Sight Mk 8 was first introduced to the fleet, lamps available had insufficient candlepower to provide a visible image against a background of high light intensity. To overcome this condition, all sights were equipped with a sunfilter. As a result of redesigning the lamps to provide better illumination, the need for sunfilters has been eliminated and, accordingly, sights equipped with sunfilters have largely disappeared from the fleet.

Special Sight Gunnery Reticles

As the background light intensity at the target decreases, the need for reticle illumination also decreases; and, for this reason all sights are equipped with a lamp rheostat for controlling illumination intensity. However, with the advent of night gunnery, the reticles provided in the Illuminated Sight Mk 8 were too large and tended to destroy the night vision of the pilot. Inasmuch as the information supplied by the radar search always made the target appear in such a location that there was a very small relative motion with respect to the target and the attacking aircraft, there was no need for a large reticle. Accordingly, a reticle with a very small reference pattern was developed for use in visual night gunnery. However, this pattern was not satisfactory under daylight conditions encountered in dawn and dusk patrols, and consequently a compromise reticle pattern was developed and issued for fleet use. This then led to the development of a sight in which the pilot could select any one of three patterns. This sight is furnished as the Illuminated Sight Mk 20 and Mods.

Adjustable Reflectors

One of the first methods for adjusting the reticle pattern in elevation was moving the reflector plate. It must be remembered that a ½-degree change in the position of the reflector plate will change the reticle image location by 1 degree or 17.4 mils. Recall that a change of 17.4 mils means a difference of 17.4 feet at a distance of 1,000 feet—an appreciable difference for many targets. Thus, a requirement for any adjustable reflector is that it be capable of a very fine adjustment and also of maintaining such adjustment. With a movable reflector, the sight pipper can be offset from the boresight reference of the plane to compensate for the trajectory of a rocket or bomb.

Lead-Computing Sights

Our discussion of sights to this point would indicate that the pilot or gunner has to determine the amount of offset, or lead, to allow in looking through the sight at the target. At slow speeds and close range, and with some practice, the problem of discovering the correct lead and hitting the target is not a very serious one. However, as speed increases, the problem of just where on a reticle to place the target to be attacked becomes increasingly difficult.

As you know from the previous chapters of this course, there are many factors to consider in determining the correct lead to obtain a hit. The need, therefore, for a sight that will do all the computing and require only that the gunner or pilot keep the target in the reticle is evident.

FREE GUNNERY.—By using a "restrained" gyro to measure the lead angle and measure the relative closing speed, the British RAF developed a lead-computing sight which, with the addition of ballistic and kinematic information, was able to solve the gunner problem. The Navy's production version of this sight became the Gunsight Mk 18 Mod 0. It was intended for free gunnery stations equipped with caliber .50 guns.

With a change in service ammunition, which had improved ballistics, all Mod 0 sights were reworked to Mod 4, to provide the proper solution. On this sight, altitude and own-plane speed are manually set in. Range is stadiametrically measured by recognizing the target wingspan, setting that in the sight, and then spanning the target by adjusting the reticle diameter. This adjustment is accomplished by means of pedal operating mechanical cables. Angle of fire is measured by the use of devices which measure both elevation and azimuth angle.

The mechanical cables required for ranging create an appreciable maintenance problem. Accordingly, a gunsight eliminating the cables and replacing them by an electrically operated range unit has been designed and produced. This is known as the Gunsight Mk 18 Mod 6.

FIXED GUNNERY.—As great as the need was for a computing sight for gunners, the need for such a sight to help pilots solve the gunnery problem was even greater, inasmuch as the pilot also flies the airplane. Accordingly, the sight was quickly adapted for pilot's use. However, the big problem to be solved was that of ranging. The gunner accomplished this by means of his feet. Since the pilot already had a job for his feet, this new task was accomplished by having his left hand rotate the throttle. Rotation of the throttle would then mechanically operate the ranging mechanism. This was introduced to the fleet as the Gunsight Mk 23.

The Mk 23 was much simpler than the Gunsight Mk 18 in that the guns always fired in line with the aircraft flight. This eliminated the need for an allowance due to angle of fire with respect to aircraft flight. Further, the fixed position of the guns also greatly decreased the error due to own-plane speed. In addition, altitude correction was eliminated to decrease the number of settings that the pilot was required to feed in. The pilot was required to fly his plane properly, set in the target wingspan, and stadiametrically range in a smooth manner.

Fire Control Systems

As different reticle positions were required if the Gunsight Mk 23 was to be used for rocket firing and bombing, a slight change in the sight would be required to incorporate such provisions. With such a change, the equipment would no longer be a gunsight but, as it would control the release of three different types of weapons, it would truly be an aircraft fire control system. The system as finally evolved became the Aircraft Fire Control System Mk 5 Mod 0.

At a later date, it was decided to omit the toss-bombing feature. This resulted in the Aircraft Fire Control System Mk 6 Mod 0. In addition to the gun and rocket firing provisions, it also will correct for temperature changes in the instrument and, by use of an aneroid assembly, correct for altitude.

Because some of the aircraft will not have rockets and to save additional weight, the basic system was redesigned. By the elimination of several of the relays required for rocket firing and manual switches, the system became Aircraft Fire Control System Mk 6 Mod 1. It is interesting to note that, basically, this system is identical with the Gunsight Mk 23 Mod 0, except for the improvements that have been made as a result of several design changes, such as the temperature and altitude corrections and improved gyro lubrication. A more complete discussion of these and later mods of the system will be found in the chapter of this course dealing with the Mk 6 series aircraft fire control system.

To keep pace with the improved aircraft and armament, Aircraft Fire Control System Mk 16 was developed. This system incorporates a gravity drop correction which greatly increases the range at which the pilot can begin firing—and still get hits.

The Aircraft Fire Control System Mk 16 is a lead pursuit day system for the aiming of fixed, forward firing guns and rockets. One of the advantages provided by this system is that it is not limited to any one type of armament. The system will accurately compute the point of aim for any service type of gun and rocket in either air-to-air or air-to-ground combat. Gun or rocket ammunition changes are incorporated into the system by the substitution of appropriate plug-in ballistic elements. The system can be transferred from the control of gunfire to rockets and from air-to-air to air-to-ground operations at the option of the pilot, resulting in a very versatile system.

DESCRIPTION AND OPERATION OF SIGHTS

The following subsections are devoted to the description and operation of several sights in use in the fleet today. They are presented to acquaint you with the practical application of the principles of optics as given previously. Further, this discussion is intended to aid you, as an Aviation Fire Control Technician 3, to know the types, construction, and operating principles of aircraft sights. Your duties will also require you to be able to locate and identify major components and subassemblies; plus performing operational tests and making EXTERNAL adjustments to the equipment. If more detailed information is necessary, you are referred to the appropriate *Handbook of Service Instructions* and *Handbook of Maintenance Instructions.*

Illuminated Sight Mk 8 and Mods

FUNCTION.—Illuminated Sight Mk 8 is used as a primary or standby gunsight in aircraft equipped with fixed, for-

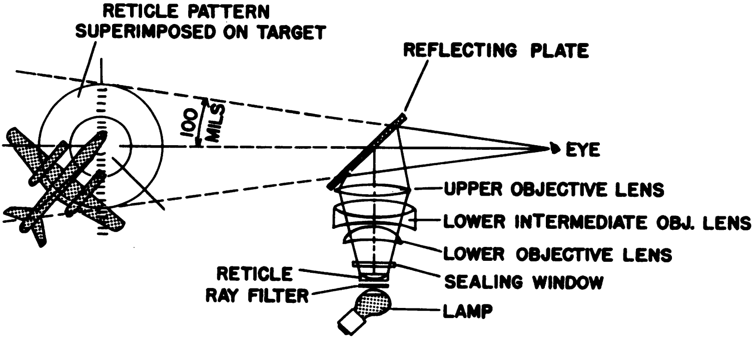


Figure 4–21.—Optical diagram of Illuminated Sight Mk 8.

ward firing guns and rockets. This sight is a collimating, reflector-type sight which contains an illuminated fixed reticle image pattern. Estimated leads are introduced by placing the center of the reticle pattern ahead of the target in the direction of the relative target motion in accordance with established doctrine. An optical diagram of the sight is shown in figure 4–21.

Figure 4–21 shows the optical system which consists of a light source, a reticle, a projection lens system, and a reflector. The paths of the light rays from the lens system to the eye are shown by solid lines. The broken lines show the apparent directions in space of the light rays from the pilot's eye.

As shown by figure 4–21, the light rays from the lamp pass through the perforated line in the metal reticle and diverge from every point on the reticle. Since the reticle is in the focal plane of the system, these diverging rays are condensed by the lens system and projected as parallel beams. These parallel bundles of rays are interrupted by the reflecting plate, where the image appears to be viewed by the eye. Since all the rays which come from a given point on the reticle and pass through the optical system are parallel, the image appears to lie always in the same direction from the observer, and at an infinite distance. The left side of figure 4–21 shows the image the pilot sees when he is on the target with an estimated lead.

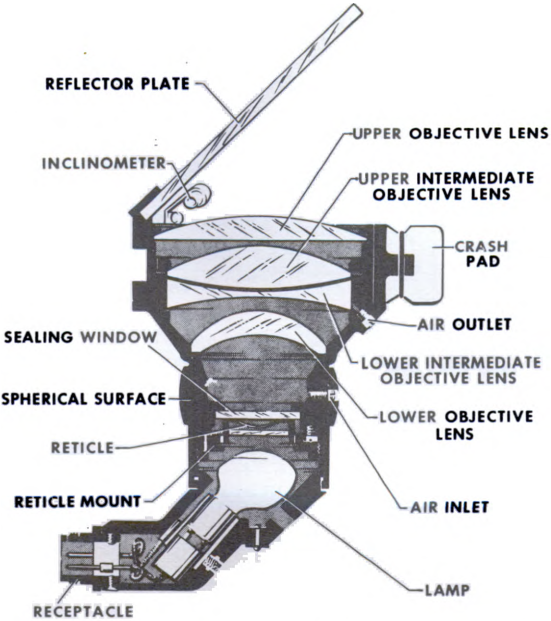


Figure 4–22.—Illuminated Sight Mk 8 (fixed reflector plate).

Description.—The construction of Illuminated Sight Mk 8 is shown in figure 4–22. Some of the modifications of the sight are without a reflector plate, with adjustable reflector plates, and with a fixed reflector plate. The sight consists of three main sections—the sight body, the lamp housing assembly, and the reflector plate mounting bracket.

1. Sight body.—The sight body consists of a dense aluminum casting which houses the reticle, filter, and projection lens system. The portion between the sealing window and the upper objective lens is made pressure tight by suitable seals and gaskets. Air inlet and outlet screws are provided for drying the interior of the pressure tight portion.

The projection lens system is comprised of the sealing window and several lenses of an objective system. These lens are mounted on seats in the sight body. They are all crown glass except for the lower intermediate objective,

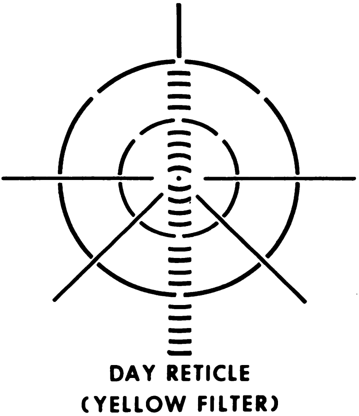


Figure 4–23.—Day reticle.

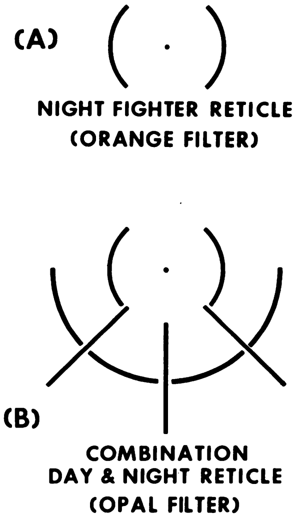


Figure 4–24.—(A) Night reticle; (B) combination reticle.

which is dense flint. Spacers, with rubber gaskets below them, are used between two lenses and their seats. Sawcuts in the spacers and holes in one retainer permit circulation of air in this pressure tight portion of the sight.

The reticle regularly supplied with the sight is shown in figure 4–23. This reticle, known as a LADDER TYPE RETICLE, is designed to accommodate rocket firing and glide and low altitude bombing as well as aerial gunnery. This reticle consists of 50- and 100-mil rings, four radial lines beginning at 10 mils and ending at 150 mils (one 90 degrees, one 135 degrees, one 225 degrees, and one 270 degrees to the vertical). It also has a vertical "ladder" at 10-mil increments.

A night reticle (fig. 4–24 (A)) and a combination night and day reticle (fig. 4–24 (B)) are also available in the supply system and may be substituted for the ladder type reticle. The night and day reticle consists of a central dot or pip, two 90-degree arcs on the 50-mil ring and the lower half of the 100-mil ring. It also has three radial lines beginning at the 50-mil ring and ending at 150 mils (one 135 degrees, one 180 degrees, and one 225 degrees to the vertical).

The reticles are made of a thin copper sheet, perforated to produce the line and figures of the reticle pattern. The reticle and colored filter are held in the mount by a retaining ring. Free circulation of air in this unsealed portion of the sight is obtained by holes in the mounts. The reticle is positioned in the focal plane of the lens system by an adapter ring machined to suitable thickness. This ring also carries a dowel with which the lower vertical lines of the reticle are oriented.

2. LAMP HOUSING. The lamp housing (fig. 4–22) is of molded phenolic plastic, and is attached to the sight body by means of a U-shaped spring clip that extends around the side and bottom of the housing. Small lips at the ends of the clip engage a groove in the interior of the sight body. The lamp housing can be detached from the body by pressing the clips in toward the housing and then dropping the housing down. To facilitate the installation of the sight and wiring of the lamp circuit, the angular position of the lamp housing can be varied.

The lamp housing contains the lamp, lamp socket, wiring, and a three-pronged receptacle. The lamp socket has two pins and a common ground which is the metal shell of the socket. This socket is connected to the three-pronged receptacle by three wires. A mating connector is necessary for external wiring connections to the power supply.

The bulb of the lamp used in this sight is elliptical in shape and carries a silver finish over its entire surface except for one spot. This spot which is a ⅞-inch diameter frosted spot is on the side where the lamp is inserted adjacent to the reticle. Using the regular aircraft 28 volts, the lamp is of double filament construction. Each filament is rated at 21 candlepower with only one filament in use at a time. This uniformity of lamp illumination increases the gunner's eye freedom, because the brightness of the reticle image remains constant throughout the range of possible eye movement.

The intensity of the bulb in use is sufficient to permit viewing the reticle pattern when exposed to bright daylight conditions. This eliminates the necessity of providing sun-filters previously supplied.

3. THE REFLECTOR PLATE MOUNTING. The reflector plate mounting bracket is attached to the top of the sight body with an inclinometer mounted on the bracket. In modifications of this sight where a reflecting plate is not used, a ring is designed to mount only the inclinometer and the buffer. The inclinometer is used by the pilot to determine when his aircraft is in a skid. The inclinometer is a liquid-filled glass tube constructed in the shape of an arc. A black glass ball sealed inside the tube indicates the lateral attitude of the aircraft during sighting operation. The inclinometer vial is supported in its thin metal bracket by means of rubber sleeving to prevent any strain from being transmitted from the bracket to the glass.

The fixed reflector plate is plano-parallel and is supported by a cylindrical mount with a 45-degree machined top edge. The lower half of the glass plate is brought flush with this edge by resting on the machined edge of the plate support, and is held by a retainer. Between the retainer and the reflecting plate is a cork gasket, cemented to the retainer. Four screws secure the reflecting plate mount to a flange on the sight body.

Adjustable Reflector Mk 4 Mod 0 includes a reflector plate assembly, inclinometer vial assembly, a mechanism for tilting the reflector plate, and a mounting base for holding the instrument to the sight body. A rubber crash pad is secured to the mounting base. Figure 4–25 shows the Illuminated Sight Mk 8 with Adjustable Reflector Mk 4 Mod 0.

Rotation of the knurled ring causes the reflector plate to tilt. Tilting of the reflector plate causes a shift in elevation of the collimated reticle image. The angular shift in degrees of the reticle image from zero setting is shown on the scale inscribed on the knurled ring. This scale covers approximately 29 angular degrees movement of the line of sight, graduated in 0.2-degree increments. The angular movement allows 4 degrees elevation and at least 25 degrees depression of the line of sight with respect to the detented position of the reflector plate. The detented position is the reference position called the boresight datum line. The aircraft's boresight datum line is a horizontal reference line that is used in the boresighting of guns and sights. An understanding of a detented position can be realized by visualizing the channel selector knob on a TV set. Each channel has its own detented position.

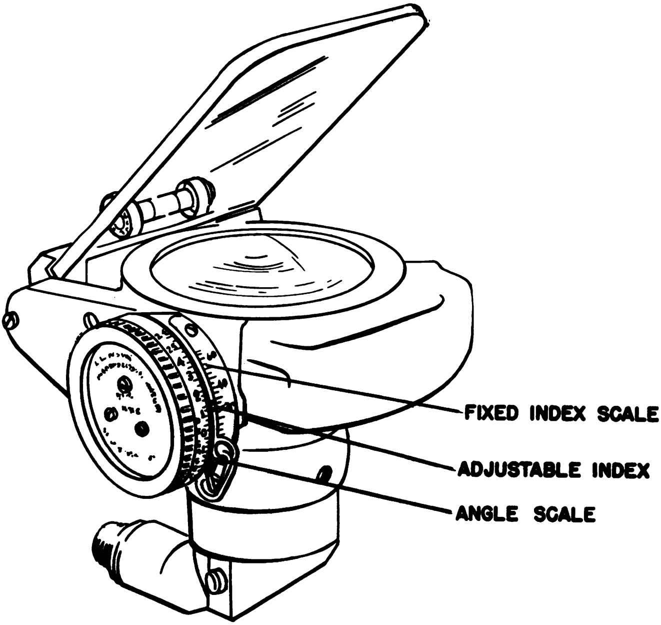


Figure 4–25.—Illuminated Sight Mk 8 Mod 8 with Adjustable Reflector Mk 4 Mod 0.

Alongside the knurled ring is an adjustable index fitted with a spring brake to hold the index in any position in which it is set. (See fig. 4–25.) A fixed index scale, graduated in mils, is fastened to the tilting mechanism housing and is so located that the zero reading matches the zero of the angle scale when the knurled ring is in its detented position. The fixed index scale is graduated in 5-mil increments from 70 mils elevation to 70 mils depression of the line of sight.

Some installations use Adjustable Reflector Mk 7 Mod 0 which is designed for inverted installation of the sight. Its construction and use is similar to Adjustable Reflector Mk 4 Mod 0 except that the limits of the reflector plate settings are changed to permit reading in the inverted position of the sight.

A flange on the reflector plate mount supports a crash pad of soft rubber for the protection of the pilot's head. The crash pad, if installed, is lashed to the flange with a stout waxed cord.

The differences between the several mods of the Illuminated Sight Mk 8 have been the result both of improvements and of differences in manufacturing techniques. The latest in the series are the Mods 12 and 13 which present a fixed reticle pattern which can be offset in elevation a plus or minus 65 mils. The Mod 12 has a day reticle pattern while the Mod 13 presents a night pattern.

OPERATION.—Operation of the sight is accomplished by turning the switch that controls the power to the lamp circuit to the ON position and adjusting the dimmer rheostat for proper illumination of the reticle.

On the sights equipped with adjustable reflectors, the reticle image may be offset in elevation above or below the reference line by rotating a knurled ring on the side of the sight. This offset in elevation is used in fixed gun strafing, rocket fire, or bombing. The amount of the offset of the center pip from the zero reference (boresight datum line) is indicated on a scale on the adjusting ring calibrated in mils. When the zero markers are alined, the line is at zero setting (or boresight datum). A detent is provided at the zero setting to permit rapid resetting of the center pip to this zero reference for aerial gunnery.

MAINTENANCE.—Illuminated Sight Mk 8 must be given proper attention to keep it serviceable and ready for operation. Maintenance should be performed by technicians who are thoroughly familiar with the sight. If overhaul is necessary, the instrument should be replaced and returned to the repair depot for reconditioning.

Preceding each flight in which the sight is to be used, a

DAILY PREFLIGHT INSPECTION should be performed. The following is such an inspection:

1. Examine the sight for tightness of installation in the aircraft.

2. Inspect each side of the windshield or reflector plate and the surface of the upper objective lens. If the surfaces are dirty, they should be cleaned.

3. Remove the lamp housing assembly from the sight by pressing in on the spring clips and moving the housing down. Examine the lamp; if it shows signs of blackening, the lamp should be replaced.

4. Energize the lamp circuit and note that a reticle image pattern is visible on the reflector. Operate the filament selector switch to the other position and observe that the image is still visible.

5. Adjust the dimmer rheostat through the full range and observe that the intensity of the reticle image varies correspondingly.

6. If possible, sight on an object at a distance of at least 500 feet. The reticle image should appear clearly defined and without parallax. To inspect for parallax, move the eye from side to side over the diameter of the lens. There should be no apparent shift of the reticle image with respect to the target as the eye is moved. If the image shifts more than one mil in any direction, the optical system is out of collimation, and the sight should be replaced.

7. Check the inclinometer ball to see that the ball is positioned with the center index mark on the vial when the aircraft is level along the lateral axis. The vial can be shifted in the rubber mounting sleeves, and if this adjustment is insufficient, the metal mount of the inclinometer may be bent a slight amount to obtain the correct alinement.

Two common maintenance procedures with which you should be familiar are the cleaning of optical surfaces and the removal of internal fogging of the lens systems.

The reflector and the lenses of the sight are polished **OPTICAL SURFACES** and should be given proper treatment in **CLEANING.** Fingerprints and water will tend to pit the optical surfaces if left for an extended time.

If the surfaces are dusty, they can be cleaned by using a fine camel's-hair brush or by wiping lightly with lens tissue. If the surfaces are oil-streaked or smudged, they can be cleaned, using a soft, clean cloth or lens tissue dampened with a solvent. Organic solvents such as alcohol, benzene, ether, and acetone can be used provided they are pure and do not leave a residue of gum or grease upon evaporation.

If the lenses of the projection system show FOGGING, remove the inlet and outlet screws and their washers. These screws are in the rear of the sight body. Force dry air into the instrument through one of these openings while holding the finger over the other to permit a pressure of approximately 5 pounds per square inch within the instrument; then remove the finger from over the outlet to allow the air in the instrument to escape. Repeat this procedure, applying the slight pressure within the sight and exhausting until the lens show no moisture. Replace the washers and screws.

As Aviation Fire Control Technician 3, you will also be responsible for the boresighting of Illuminated Sight Mk 8 and Mods. The procedures for boresighting are covered in a separate chapter of this course.

Illuminated Sight Mk 20 Mod 0

FUNCTION.—The Illuminated Sight Mk 20 Mod 0 is basically the same as the Illuminated Sight Mk 8 in that light passes through a reticle, collimated, and presented as a reticle pattern on the windshield. (See fig. 4–26.) It differs in that the reticle is mounted on a turntable which can be rotated to present any one of three different patterns. This sight is used in aircraft equipped with fixed, forward firing guns and rockets. It is also utilized for low altitude bombing and both day and night operation.

The present sights are equipped with a standard ladder type 50- and 100-mil reticle as used in daylight operations, a small 50-mil reticle for night use, and a combination or compromise reticle for light conditions as encountered at dawn or dusk. (See figs. 4–23 and 4–24.) Each pattern

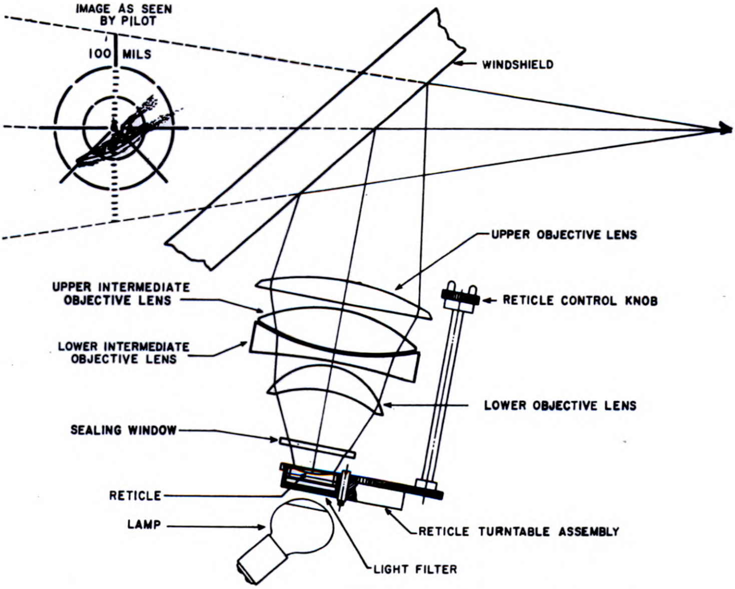


Figure 4–26.—Illuminated Sight Mk 20 Mod 0 optical system.

with its respective light filter can be readily positioned for use by the pilot.

DESCRIPTION.—Similar to the Mk 8, the Illuminated Sight Mk 20 Mod 0 consists of three main sections—the sight body, the lamp housing assembly, and the inclinometer-and-crash-pad assembly. The differences between the sights lie in the fact that the Mk 20 Mod 0 has a reticle turntable assembly and utilizes the windshield as a reflector plate.

The RETICLE TURNTABLE-AND-BRACKET ASSEMBLY (fig. 4–27) contains the three reticles and their light filters. The turntable-and-bracket assembly provides a means for moving each of the three reticles and filters into the focal plane of the optical system, thus providing the pilot with a selection of reticle image patterns.

The RETICLE TURNTABLE resembles a large flange spur gear. The top surface is recessed to receive the reticles and their mounts, and has three equally spaced holes into which the tinted glass light filters are mounted. The reticle disks

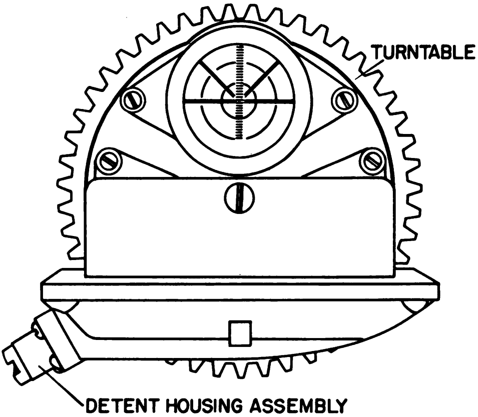


Figure 4–27.—Turntable-and-bracket assembly.

are attached to the reticle mounts, which, in turn, are assembled into the recessed section of the turntable directly above the light filters as shown in figures 4–26 and 4–27.

As indicated previously, the RETICLES used in this sight are basically the same configuration, with minor differences, as the reticles used in Illuminated Sight Mk 8. One difference is found in the Mk 20 Mod 0 day reticle which has the outer circle identified by the "100 MILS" marking at the top of the pattern. The other difference is the radial lines of the day reticle start at 25 mils instead of at 10 mils as on the Illuminated Sight Mk 8.

The Illuminated Sight Mk 20 Mod 0 utilizes LIGHT FILTERS. The yellow light filter used with the day reticle allows the reticle pattern to be illuminated to a greater extent for better image visibility against light backgrounds. The red-orange light filter, used in conjunction with the night reticle, serves to decrease the brilliancy and alter the color of the pattern so that it does not obscure the target. The flashed-opal light filter used with the combination reticle provides a constant degree of illumination through a considerably wider range of eye movement than the night filter. The combination reticle, as its name would indicate, is a compromise between the night reticle and a minimum acceptable day reticle.

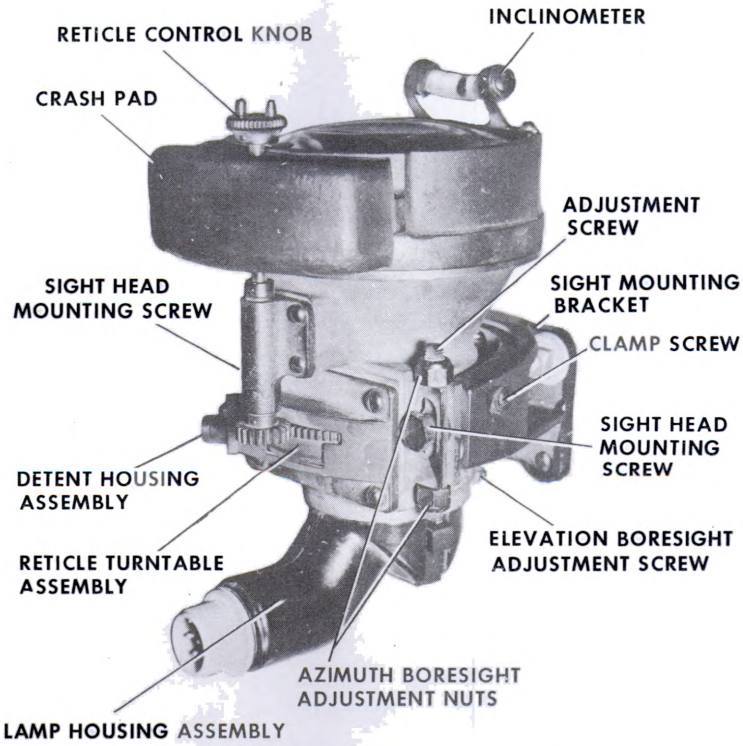

RETICLE CONTROL KNOB
INCLINOMETER
CRASH PAD
ADJUSTMENT SCREW
SIGHT HEAD MOUNTING SCREW
SIGHT MOUNTING BRACKET
CLAMP SCREW
SIGHT HEAD MOUNTING SCREW
DETENT HOUSING ASSEMBLY
ELEVATION BORESIGHT ADJUSTMENT SCREW
RETICLE TURNTABLE ASSEMBLY
AZIMUTH BORESIGHT ADJUSTMENT NUTS
LAMP HOUSING ASSEMBLY

Figure 4–28.—Illuminated Sight Mk 20 Mod 0.

The TURNTABLE BRACKET, as used on Illuminated Sight Mk 20 Mod 0, contains a horizontal slot for clearance of the turntable assembly. The turntable is assembled into the slotted bracket by means of the threaded turntable shaft. The shaft passes through a hole in the upper section of the bracket, through the bearing hole in the center of the turntable, and is screwed into the lower section of the bracket. This method of mounting allows the turntable to be rotated around its center and thus enables any of the reticles to be positioned in the focal plane of the lens system.

The TURNTABLE ASSEMBLY is positioned by a small mating pinion gear. (See figs. 4–26 and 4–27.) The pinion gear is attached at the lower end of the reticle control shaft that extends down through a bearing bracket mounted on the rear of the sight body. The upper end of this shaft contains a serrated control knob located just above the crash pad as shown in figure 4–28. Thus when the control knob is rotated, the pinion gear at the lower end of the shaft also rotates and drives the turntable assembly containing the reticles. In this manner each of the three reticles can be brought into the vertical optical centerline of the optical system and their patterns can be projected onto the windshield of the aircraft. A spring-loaded detent plunger in the detent housing of the bracket engages one of three detent holes in the turntable when the desired reticle is optically centered relative to the optical system.

Operation.—Operation of the sight is accomplished by turning the switch that controls the power to the lamp circuit to the ON position. After determination of the reticle pattern to be used, rotate the reticle control knob until the desired reticle pattern is visible on the windshield. The control knob should be turned back and forth a small amount to be sure that the reticle turntable is engaged in the detent. Next adjust the dimmer rheostat until the pattern is properly illuminated.

Maintenance.—Because of the great similarity between the two sights, the maintenance procedure given for the Mk 8 will apply to the Mk 20 Mod 0 illuminated sight with the following addition to the preflight inspection. The reticle control knob should be turned to each of the three positions. In each position note the placement of the image pip. If the pip location of one pattern varies more than one-half mil from the pip location of another pattern, the sight should be replaced.

There exists a possibility of the internal fogging of the lens system. The lens system is sealed from the atmosphere to prevent possible entrance of moisture, and is charged with dry nitrogen to replace the moisture laden air that remains in the system after the instrument is assembled. The interior of the sight is sealed during assembly. The lens system, however, does not assure permanence of the seal, and provision is made for dehydration and recharging in the field. The sight body is equipped with a gas inlet valve and an outlet plug. It is recommended that the sight body interior be thoroughly dried by recharging with dry nitrogen at intervals determined by service conditions or experience. Detailed instructions for dehydrating the lens system are given in the maintenance manuals for the sight.

Illuminated Sight Mk 20 Mod 4

FUNCTION.—Illuminated Sight Mk 20 Mod 4 has been developed from Illuminated Sight Mk 20 Mod 0. Essentially, the modification in this sight is a manually adjustable reflector plate. (See fig. 4–29.) This was done to make it possible to offset the line of sight from the boresight datum line. Minor modifications consist of an additional elevation boresight screw and two lock bushings which are substituted for the mounting springs on the Mod 0 to reduce the vibrations of the sight body in the mounting bracket during flight.

The adjustable reflector plate is mounted on the sight so that its angle of inclination can be varied within limits of 75 mils up and 350 mils down to offset the line of sight required for the release of different kinds of armament. During a single mission, by rotating an adjusting knob to one of two preset detent positions, the line of sight can be changed rapidly and accurately to the offset required for fixed gun firing and the releasing of rockets, bombs, or any combination of three kinds or sizes of armaments. Between missions, detent positions can be changed easily to preset the sight for the offsets that will be required for other kinds and sizes of armament that may be used during the next mission.

DESCRIPTION.—Because of the similarities between Illuminated Sights Mk 20 Mods 0 and 4, the description given previously for the Mod 0 also applies for the Mod 4. Therefore, it is only necessary to discuss the adjustable reflector assembly which forms the principal difference between the two mods.

The adjustable reflector plate, the adjusting knob for setting the inclination angle of the plate, and the aluminum

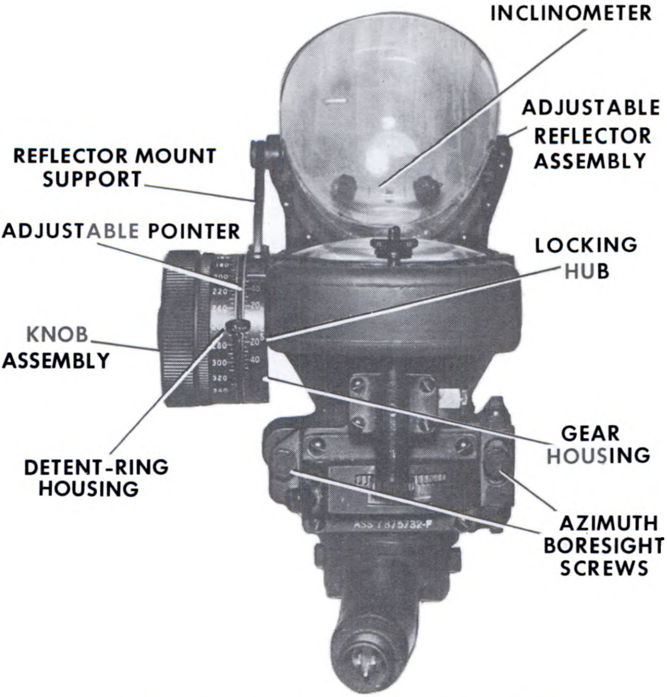


Figure 4–29.—Illuminated Sight Mk 20 Mod 4.

mounting ring on which these parts are supported comprise the adjustable reflector assembly. (See fig. 4–29.) The oval shaped reflector plate, made of optical plate glass, reflects the reticle image from the sight to the eyes of the pilot. The mounting frame for the reflector plate and the inclinometer is pivoted on the mounting ring so that the inclination angle of the plate can be varied.

The angle of the reflector plate is established by the reflector mount support located on the left-hand side of the sight. (See fig. 4–29.) The lower end of the support passes into the gear housing. Here, the rear edge of this lower end has teeth that mesh with those of a pinion gear. Thus, when the detent-ring housing is rotated, the pinion gear turns and raises or lowers the reflector mount support. This changes the inclination angle of the reflector plate.

The principal parts of the adjusting knob (fig. 4–29) are located on the left side of the mounting ring. They consist of the gear housing, the detent-ring housing, and the knob assembly. The gear housing is secured to the mounting ring; the detent-ring housing is mounted on the gear housing; and the knob assembly is secured to the detent-ring housing.

The gear housing and the detent-ring housing have scales engraved on their surfaces. The scale of the gear housing is engraved at 5-mil intervals from 0 to 50 mils up and from 0 to 50 mils down. The scale of the detent-ring housing is engraved at 5-mil intervals from 0 to 75 mils up and from 0 to 350 mils down. When the zero marks of the two scales are alined, the zero detent is engaged and the inclination angle of the reflector plate is 45 degrees.

An adjustable pointer (fig. 4–29) is secured to a wire ring located between the gear housing and the detent-ring housing. The ring slides in a groove around the adjusting knob. By squeezing the finger grips, the wire ring is loosened and can be easily slipped until the pointer is opposite any position of the fixed scale on the gear housing.

The adjustable pointer makes it possible to have the engraved markings of the two scales separated so that, when visually adjusting the inclination angle, the desired scale position can be seen easily and setting can be done rapidly and accurately. In addition, the adjustable pointer increases the usability of the sight. By presetting the pointer position and the two adjustable detent positions, it is possible to establish rapidly three preset offsets of the line of sight.

The gear housing is constructed to support and guide the reflector mount support. It contains a shaft and gear to drive the reflector mount support when the adjusting knob is turned.

The detent-ring housing, secured to the end of the pinion gear outside the gear housing (fig. 4–29), contains the three detent plungers that engage the groove in the cover plate of the gear housing. When a line-of-sight offset is to be made, the detent-ring housing is rotated until the required detent plunger is engaged.

The principal parts of the detent-ring housing are three concentric metal rings, an adjustment plate, and a shaft hub. (See fig. 4–30.) Each of these concentric rings has a hole drilled in its edge to accommodate a detent plunger and spring. The detent hole in the outer ring is drilled directly beneath the zero position of the scale so that the detent is engaged when the zero marks of the movable and fixed scales are alined.

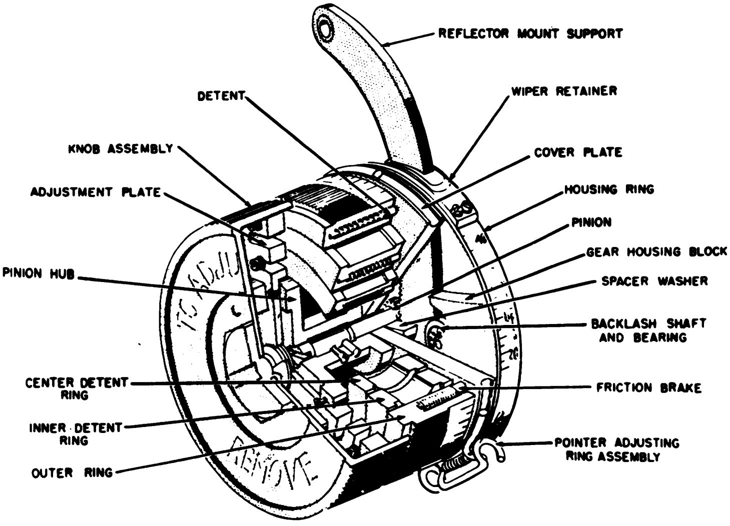


Figure 4–30.—Detent assembly section.

The center and inner detent rings are made to slip inside the outer ring (fig. 4–30). This enables them to be rotated with respect to the outer ring and makes it possible to vary the positions of their detents relative to the zero mark on the movable scale. Each of these two detent rings is secured to the adjustment plate with two bright screws and washers. The adjustment plate has six slots opposite the edge of both the center and inner detent rings. Both rings are tapped in several places for the two screws that secure them. If its detent is engaged and the two bright screws are loosened or removed, the ring can be preset to any offset position by rotating the adjusting knob. When the scale is alined to the mil offset desired, the two bright screws are replaced and/or tightened.

The shaft hub is secured with four screws to the adjustment plate. (See fig. 4–30.) The hub fits on the end of the pinion and is secured to it with a setscrew and taper pin. Recall that movement of the pinion gear results in changes in the angle of the reflector plate.

The knob assembly is a cover for the left end of the detent-ring housing. Its flanged rim is serrated to provide a non-slip grip for rotating the detent-ring housing to set the offset angle. The knob assembly is also secured to the adjustment plate which is connected to the reflector plate through the pinion gear and the shaft hub. Thus, you can see how the knob assembly controls the angle of the reflector plate, and the position of tightening the detent rings to the adjustment plate determines the offset positions.

OPERATION.—Operation of this sight is accomplished by turning the switch that controls the power to the lamp circuit to the ON position. The appropriate reticle pattern is then selected by rotating the reticle control knob. Next adjust the dimmer rheostat until the pattern is properly illuminated. If the reticle image is not visible when the lamp circuit is energized, change the contact position of the filament selector switch. If possible, the defective lamp should be replaced before takeoff of the aircraft.

The final step in the operational procedure involves the difference between the Illuminated Sight Mk 20 Mod 4 and the Mod 0. Because of the adjustable reflector plate, it is advisable to preset the detent positions of the adjusting knob for the line-of-sight offset that will be needed to establish the flight attitude required for the ballistics of the armament to be released.

The following method is for DETENT ADJUSTMENT. A wrench and screwdriver are the only tools necessary to set the positions of the adjustable detent rings.

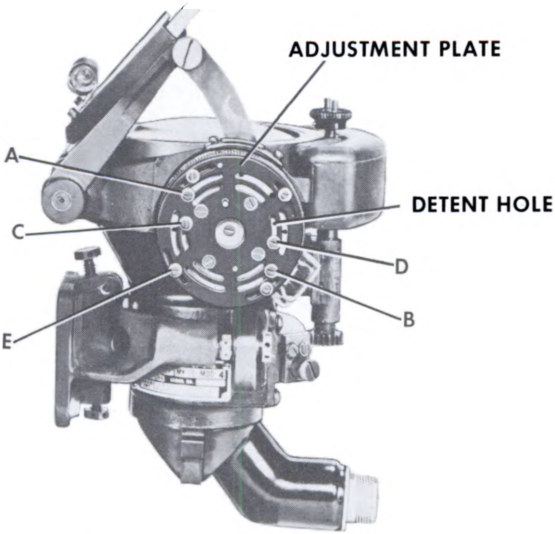


Figure 4–31.—Illuminated Sight Mk 20 Mod 4, detent adjustments.

1. Using a wrench, unscrew the knob screw and remove the knob assembly from the detent ring. (See fig. 4–29.)

2. Set the adjustable pointer to the zero mark of the fixed scale.

3. Rotate the detent-ring housing until the detent nearest to the desired scale setting is engaged.

4. Refer to figure 4–31. Loosen the two bright screws (A and B or C and D) that secure the engaged detent ring to the adjustment plate. ***Caution:*** Do not loosen the four black screws (E) that secure the adjustment plate to the outer ring. This would cause misalinement between the reflector plate and movable scale.

5. Rotate the detent-ring housing until the desired setting of the movable scale is opposite the adjustable pointer.

NOTE: If the detent-ring housing cannot be rotated far enough to make the setting, remove the two loosened bright screws and lockwashers, then rotate it to the desired scale setting.

6. Replace the bright screws and lockwashers and tighten them to secure the adjustment plate to the detent ring.

NOTE: If it has been necessary to remove the two bright screws and lockwashers to make the scale setting, look into the slots of the adjustment plate and locate two screw holes in the engaged detent ring. Insert and tighten the two bright screws and washers. Notice that the holes in which the two screws are replaced are not the holes from which they were removed. Screw holes are spaced along the edge of the detent rings so that two holes for the screws always are accessible through two of the slots in the adjustment plate.

7. Position the knob assembly on the detent-ring housing and secure it with the knob screw.

MAINTENANCE.—The maintenance information given under the Illuminated Sight Mk 20 Mod 0 is applicable to the Mod 4 sight. However this information should be supplemented by the following:

1. The daily preflight inspection should also include rotation of the adjusting knob through its entire range to make certain that the detents engage and that they are positioned to establish the line-of-sight offsets to be required during the mission. The adjustable pointer should be moved in order to determine that its ring is tight and will not slide from its preset position as the result of vibration. Notice that the movable and fixed scales are legible and that the knob assembly is held securely in place by the knob screw.

2. The reflector plate should be cleaned in accordance with information given under the Illuminated Sight Mk 8 section of this course.

3. If the preflight inspection has disclosed operational failures or serious physical damage, the sight should be replaced and returned to an overhaul shop for reconditioning.

Sight Unit Mk 6 Mod 1, Amplifier Mk 53 Mod 0

Function.—The Sight Unit Mk 6 Mod 1 (fig. 4–32) is a universal, reflector-type sight for use in aircraft employing fixed, forward firing guns, rockets, bombs, or other weapons. This sight unit is mounted forward of the pilot and targets are viewed through the windshield, on which one or two reticle images are projected by the sight unit. The reticle images, being focused at infinity, appear to be projected or superimposed on the target. A fixed sight line, which indicates the direction the aircraft is pointing, is established by the center of the fixed reticle image. The other or movable image establishes a sight line which is automatically offset from the fixed sight line in azimuth and elevation by amounts determined by the computer installed in the aircraft.

The Amplifier Mk 53 Mod 0 (fig. 4–33) is required to

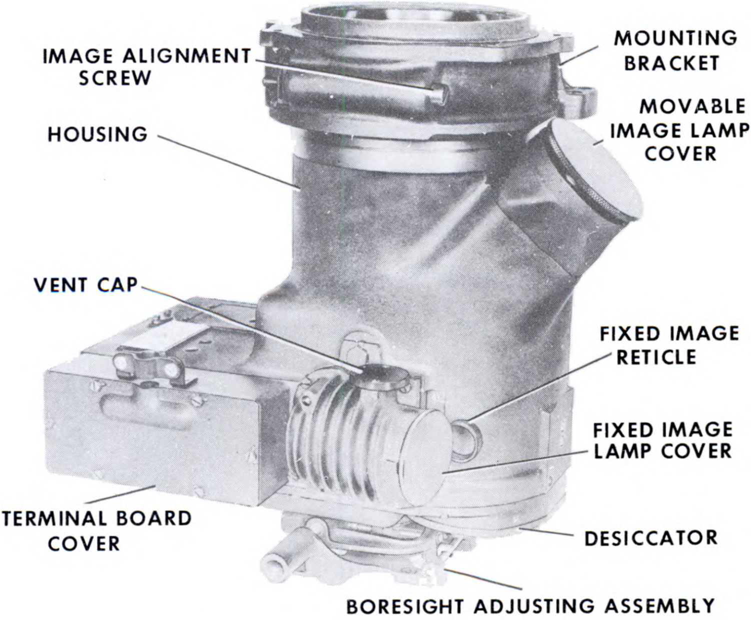


Figure 4–32.—Sight Unit Mk 6 Mod 1.

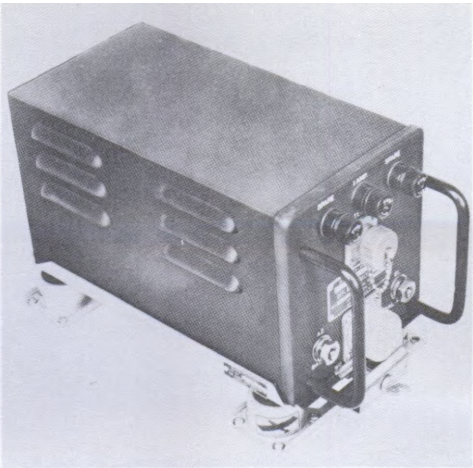


Figure 4-33.—Amplifier Mk 53 Mod 0.

control the servomotors of the sight unit so as to position the movable pip in a manner determined by the computer. The amplifier is installed at any convenient location in the aircraft, and is electrically interconnected with the sight unit, a computer, a power source, and a suitable control box.

It should be pointed out that as the eye is moved further back from the collimating lens, the apparent size of the reticle image remains unchanged, but the APPARENT size of the lens aperture is REDUCED. An aperture can be defined as an opening admitting light. An analogy to this situation would be the change in area seen through a keyhole as you backed away. Thus, the further the distance between eye and windshield, the more the head movement required to see the computing pip for the full range of lead angles. Using the 5-inch optics, the permissible eye distance is greater than smaller optics. (Analogy: larger keyhole, further away, same sight area.) This is of importance, for the pilot can sit further away from the lens and still see all the lead angles when using 5-inch optics.

The fire control system determines the corrections needed for the solution of the fire control problem. Thus the sight unit provides the pilot with a means of aiming his aircraft

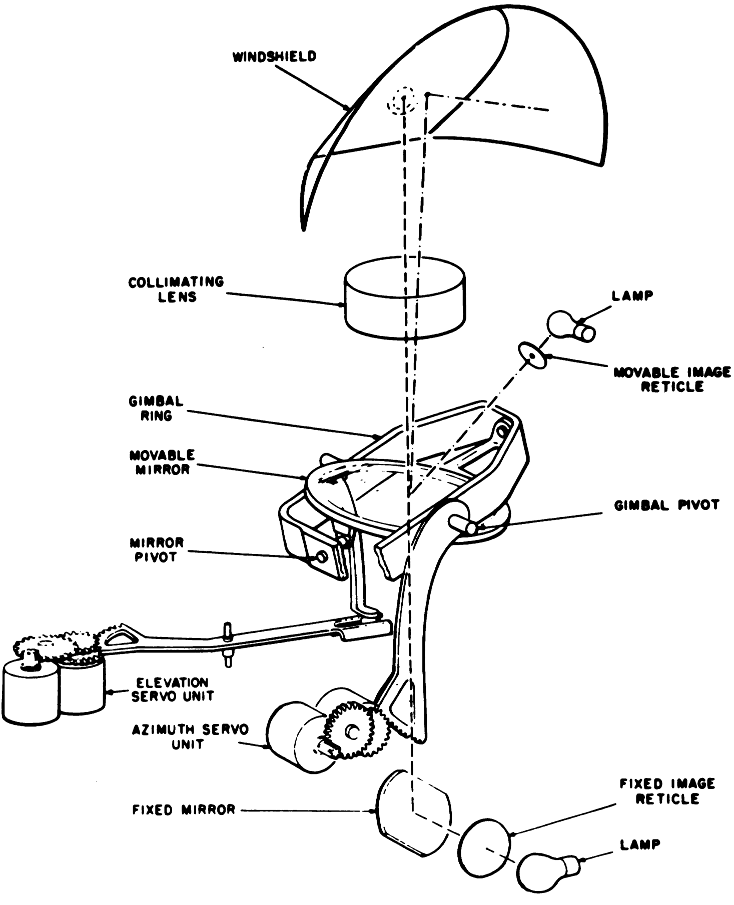


Figure 4–34.—Mechanical schematic diagram of Sight Unit Mk 6 Mod 1.

to include these corrections before firing or releasing his weapons. Depending on the mission and the type of weapon being used, any one of several computers may be selected for electrical interconnection with the sight unit and the amplifier.

Description.—The Sight Unit Mk 6 Mod 1 consists of a lens assembly, a fixed and a movable image reticle, a fixed and a movable image mirror, the movable mirror linkage, an elevation and an azimuth servo unit, a desiccator, and a terminal board assembly. Figure 4–34 shows a mechanical schematic diagram of the sight.

The LENS ASSEMBLY consists of a barrel and several retaining rings supporting two double lenses separated by an airspace. The airspace is open to the inside of the sight unit, but not to the atmosphere, as the upper lens is sealed at assembly. Light rays from any point on the reticle which forms the image are collimated by the lens assembly and are parallel when they leave the upper lens, making the image appear to be at infinity. Thus, the two objects to be brought into coincidence—reticle image and target—appear to be in the same plane, and the eye accommodates itself to both objects simultaneously without difficulty. The lens assembly cannot be removed from the sight unit without breaking the seal.

The FIXED RETICLE IMAGE, when illuminated, is projected up through the collimating lens of the sight unit and reflected off the windshield to give a line of sight corresponding to zero lead angle. Illumination is obtained by use of a double-filament 100/100 candlepower lamp. The projected fixed image consists of a circular pip, a concentric circle of 50-mil radius and, in the lower part of the field of view, a half circle of 100-mil radius. (See fig. 4–35 (A).)

The reticle for the MOVABLE IMAGE is permanently mounted just beneath the lamp used to illuminate it. Illumination is obtained by the use of a double-filament 21/21 candlepower lamp. The projected movable image is a circle of 6-mil internal diameter as shown in figure 4–35 (B). The movable reticle image is projected through the same lens and, when the lead angle signals from the computer are zero, its position on the windshield coincides with the center of the fixed reticle image.

The FIXED IMAGE MIRROR is permanently mounted in a position to reflect the fixed reticle image up through the lens assembly at zero lead angle. The reflected light rays pass through a semitransparent movable mirror which is mounted above the fixed mirror. This physical arrangement has been

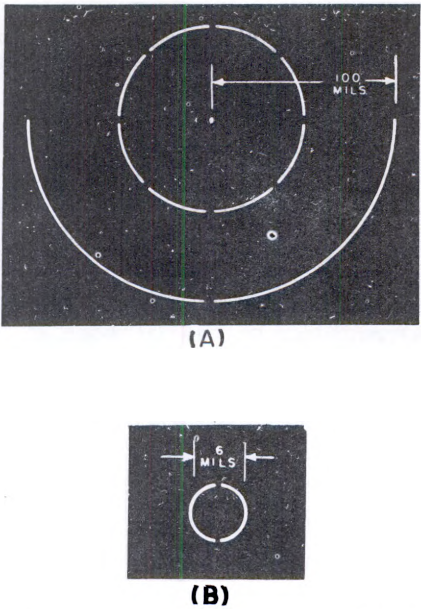


Figure 4–35.—(A) The fixed image reticle pattern; (B) the movable pattern.

adopted in order to allow projection of both images at the center of the field of view. (See fig. 4–34.)

The MOVABLE IMAGE MIRROR (semitransparent) is mounted on a frame which is pivoted in such a manner as to provide apparent elevation motion of the image. (See fig. 4–34.) The frame pivot supports rest in a gimbal which is pivoted, in turn, to provide apparent azimuth motion of the image. The gimbal pivots are supported in the housing of the sight unit. At midtravel point in both azimuth and elevation, the mirror is so positioned that the reticle image is reflected up through the lens assembly and projected at the optical center of the lens assembly. The semireflective coating on this mirror provides for equal brilliance of the transmitted fixed image and the reflected movable image.

The MOVABLE MIRROR LINKAGE is the means provided to convert the information from the fire control system into movement of the reticle image. Rotation of the azimuth servo rotor, by a signal from the fire control system, causes movement of the gimbal ring through a gear and arm arrangement. The movement of the gimbal ring results in a repositioning of the movable mirror and thus azimuth movement of the reticle image. Rotation of the gimbal (azimuth motion) does not alter the elevation position of the reflected image.

In a like manner, rotation of the elevation servo rotor is converted into movement of the movable mirror through a system of gears, arm and roller assembly, guides, and angular arm. Rotation of the mirror (elevation motion) does not affect the azimuth position of the reflected image. Thus when lead angle signals are generated by the fire control computer, the movable mirror is tilted in azimuth, elevation, or both. This causes the movable reticle image to shift its apparent position on the windshield.

The SERVO UNITS for azimuth and elevation are identical except for their mounting positions and gear ratios. Each unit consists of a servomotor and a synchro control transformer mounted in a housing with the necessary gearing. When proper aiming requires a change of image position, the computer mechanism turns the rotor of a synchro control transmitter which is electrically connected to a synchro control transformer in the sight unit. (See fig. 4–36.) The resulting angular displacement between synchro rotors (transmitter and transformer) supplies an error signal to the amplifier. This extremely weak signal is amplified and provides power to a sight unit motor which drives the synchro rotor (transformer) until the angular displacement with respect to the computer synchro rotor is zero. In other words, any angular difference between transmitter and transformer rotors sends an electrical signal through the amplifier to the motor. This signal causes the motor to rotate until the angular difference disappears.

Since the motor is connected to the movable mirror linkage system, it also drives the mirror to a new position. Thus light will be reflected off the windshield at a different angle causing the image to shift its apparent azimuth position. Under normal operational conditions the system is never act-

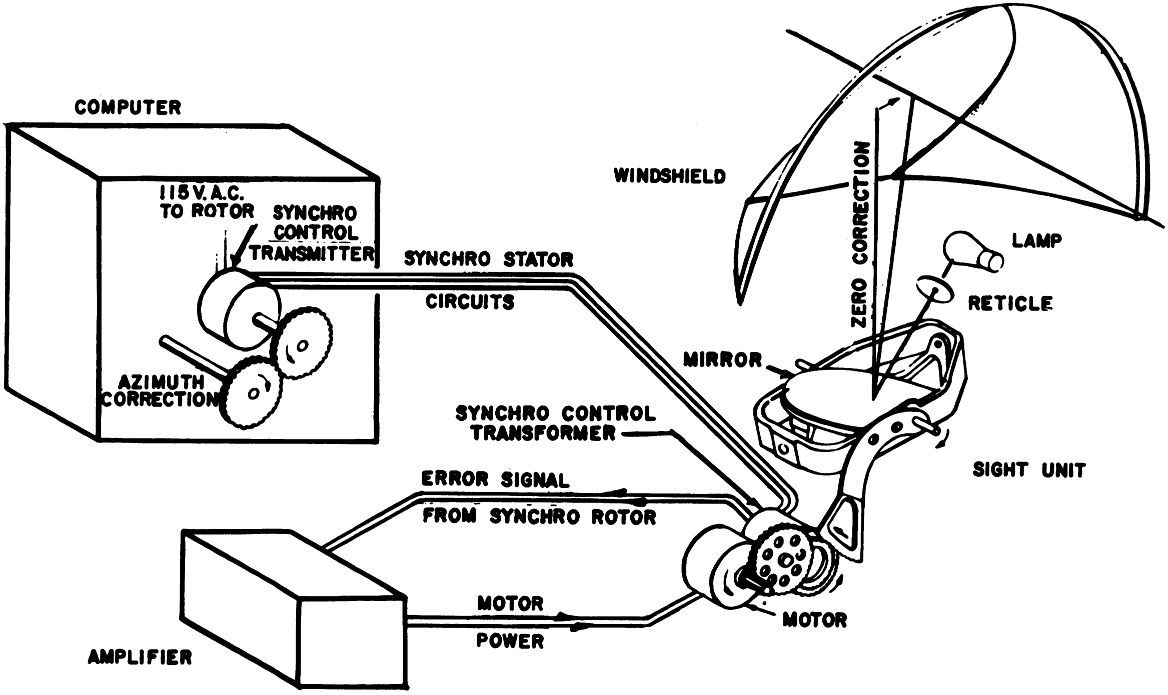


Figure 4–36.—Electrical schematic of control system, azimuth channel only.

ually still and the error signal is never zero. However, the response of the servo system is so rapid that the error is negligible at all times. Elevation motion of the movable image is produced in the same manner by means of a similar, independent, elevation system.

The **DESICCATOR** provides automatic humidity control for the sight unit. Silica gel crystals within the desiccator absorb moisture from the entering air and are automatically reactivated with a heater whenever air escapes. The desiccator allows the sight unit to "inhale" during aircraft descent and to "exhale" during aircraft ascent. When the aircraft is on the ground or in level flight, air does not leave or enter the sight unit. The operation of the desiccator is controlled by the difference between pressures existing outside and inside the sight unit. No replacement of the silica gel crystals is required, although a window allows observation of their condition at all times. The desiccator cannot be removed from the sight unit without breaking the seal.

The **TERMINAL BOARD ASSEMBLY** contains 23 terminal lugs, of which 21 carry circuits into the sight unit and 2 are extra. The terminal board cover plate is shown in figure 4–32. Removal of this plate provides access to the terminal board. The terminal board itself cannot be removed from the sight unit without breaking the seal.

AMPLIFIER MK 53 MOD 0 is a two-stage, two-channel (azimuth and elevation) unit. It builds up, or amplifies, the error signals received from the sight unit synchros and drives the servomotors in the correct direction to reduce the error signal to zero. Electrical connections to the fire control system and power supply are made through an electrical connector on the front panel. An additional connector on the front panel provides convenient access for checking input and output circuits. Input to each channel of the amplifier is furnished by a synchro control transmitter, while the output of each amplifier channel is fed to the control phase of a servomotor in the sight unit. Each channel of the amplifier can be balanced to the fire control system by means of balancing adjustments on the front panel.

OPERATION.—Operation of the sight unit and amplifier merely consists of turning ON the switches that supply power to these units. This should be done approximately 3 to 5 minutes before the fire control system is used. The reason for this is to allow time for the amplifier to warm up. The reticle image lamps should then be turned ON and adjusted for the required brilliance. The fixed image may be illuminated or not, as desired.

The length of time during which a target should be covered or "tracked" before firing or releasing weapons will depend on the requirement of the computer. This, of course, is essentially a problem for the pilot's operation of the system. Information concerning aiming and associated techniques is found in the manuals relating to the fire control systems.

MAINTENANCE.—The sight unit is sealed to prevent entrance or exit of air except through an automatically reactivated desiccant and should not be disassembled in the field. Sight units and amplifiers should be removed from the aircraft after 600 equipment operating hours, or when defective. After proper preserving and packing, they should be shipped to an overhaul activity.

Normally, as Aviation Fire Control Technicians 3, you will not be required to service the amplifier. This, of course, does not preclude your testing the circuits between major components for continuity, short circuits, and grounds. Fuses, jacks, cables, and wiring should be checked to make certain that the difficulty does not exist in one of them before replacement of units. Many a technician has worked long hours, employing elaborate theories, to locate a trouble and found to his chagrin that the trouble was a "blown" fuse. The old story about the striker who knew all the formulas for the equipment but did not know where the power switch was located emphasizes the necessity of the maintenance people being practical.

Warning: If in an emergency you are required to service the amplifier, note that it involves the use of voltages which can be dangerous to life. Suitable precautions must be observed if power is on and electrical readings are taken with the dust cover removed. Do not change tubes with the power on. Under certain conditions dangerous potentials may exist when the power is off due to charges retained by capacitors. To avoid injury, always discharge capacitors by grounding terminals prior to touching them.

To determine whether the trouble is actually in the unit or in the cabling, use the schematic diagram for diagnosis and the wiring diagram for locating meter test points. Check first to see that power is being supplied to the installation and that all connectors are tightly in place. When a trouble is common to azimuth and elevation, it is unlikely that defective cabling has caused open circuits independently in each function. Such trouble is most likely to be caused by a failure of power or a defective unit affecting both channels.

Before each flight in which the sight unit and amplifier are to be used, a DAILY PREFLIGHT INSPECTION should be performed. The sight unit and amplifier, as parts of a complete fire control system, will necessarily be checked in accordance with the requirements of the entire system. When power is available and the type of computer installed allows convenient adjustment of artificial inputs, the checking reticle provides a simple means of determining changes in movable reticle image position. Primary checks will always be on the computer, which is the sensing element of the fire control system and which controls the extent of sight unit or amplifier operation.

One independent check which should be made on the sight unit is a lamp filament test. Throw the fire control reticle switches to NORMAL and SPARE for each reticle, and check that both filaments are good in each lamp.

Aircraft Sight System Mk 1 and Mods

FUNCTION.—The Aircraft Sight System Mk 1 (fig. 4–37) is an assembly of components designed as a general-purpose sight system for use in aiming the aircraft during air-to-air gunnery or in air-to-surface operations. The system pro-

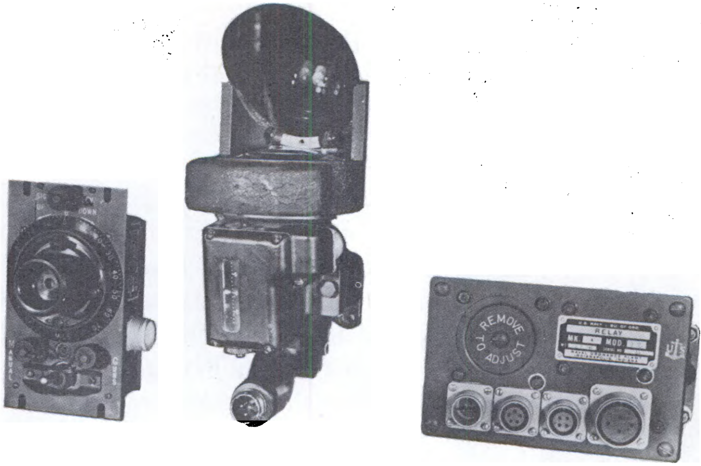


Figure 4–37.—Aircraft Sight System Mk 1 Mod 1.

vides the pilot with a reticle pattern similar to that furnished by the Illuminated Sight Mk 8, except that it is adjustable in elevation. The adjustment is made by a servomotor which is, in turn, controlled by a dial on a control box readily accessible to the pilot.

This system, used in various attack aircraft, enables the pilot to shift rapidly and accurately from gun to bomb position during air-to-surface fixed gun strafing, rocket firing, and bombing operations. It also provides a zero sight line for aiming the aircraft's fixed guns when needed for air-to-air gunnery.

Description.—There are four mods of Aircraft Sight System Mk 1. Each mod consists of three units—a relay, control box, and a sight unit. (See table 4–1.)

Table 4–1.—Components of Aircraft Sight System Mk 1

Mods	Relay	Control Box	Sight Unit
Mod 0	Mk 4 Mod 1	Mk 18 Mod 1	Mk 1 Mod 2.
Mod 1	Mk 4 Mod 1	Mk 18 Mod 1	Mk 1 Mod 3.
Mod 2	Mk 4 Mod 1	Mk 18 Mod 1	Mk 1 Mod 4.
Mod 3	Mk 4 Mod 1	Mk 18 Mod 2	Mk 1 Mod 5.

The SIGHT UNIT consists of the light source, movable reticle, and collimated lens system along with the servomechanism for operating the reticle. The mod of the sight unit may be identified as follows:

Mod 2 carries a reflector.

Mod 3 carries a reflector and a crash pad.

Mod 4 carries a crash pad.

Mod 5 carries neither a crash pad nor a reflector.

There are many similarities between this sight unit and sights already presented in this chapter. The collimating section, the use of dry nitrogen under pressure, the reticle, the inclinometer, the lamp housing assembly, the dimmer rheostat, and filament selector switch have been previously discussed. The filter used is a red-orange glass filter which provides good visibility of the image for day and night operations.

You will recall that the Illuminated Sights Mk 8 Mod 8 and Mk 20 Mod 4 used an adjustable reflector plate to control the elevation offset of the line of sight. In the Aircraft Sight System Mk 1, the reflector plate is positioned at a 45-degree angle to the optical centerline. Up-and-down variations of the sight line are obtained by a servomechanism which positions the reticle and is controlled by a dial and selector switch in a control box.

The big difference, then, in this sight unit is the method of offsetting the reticle pattern. The SERVO UNIT, which performs this function consists of a d-c reversible motor, a slide type potentiometer, a resistance followup lead screw assembly, a reticle servo screw assembly, and suitable gearing. Rotation of the motor is transmitted to both screw assemblies. The reticle servo screw assembly positions the reticle carrier while the resistance followup lead screw assembly is provided with a traveling nut. This traveling nut carries the movable contact brush of the slide type potentiometer and the sight elevation scale indicator. The slide potentiometer is connected so that it acts as one-half of a bridge circuit used in the servo circuit. The sight elevation scale is mounted on the cover of the mechanism where it is visible to the pilot. (See fig. 4–37). Thus, any rotation of the servomotor will automatically position the movable contact brush of the potentiometer, the sight elevation scale indicator, and the reticle.

The CONTROL BOX has a dial with adjustable detents for controlling the servomechanism in the sight unit. Presetting of the detents to the desired mil settings provides a rapid means of shifting the reticle to a given position. A GUNS-MANUAL switch provides for a zero sight reference when the gunnery solution is required in a hurry, as it might be in case the aircraft were "jumped" by enemy aircraft while on a bombing mission. The Control Box Mk 18 Mod 2 differs from the Mod 1 by the addition of indirect lighting for the illumination of the dial settings.

The RELAY UNIT is needed for operation of the servomechanism. It may be mounted at any convenient location in the plane's fuselage. The function of the relay is to determine the polarity of the electrical impulses originating in the control box and to relay power of the correct polarity to the potentiometer and motor of the reticle servo unit.

Three adjustment potentiometers are provided beneath the top cover of the relay unit. The potentiometers marked TRIM are used to accurately calibrate the bridge circuit resistance of the servo unit. The potentiometer marked GUNS is used to adjust the reticle for fixed sight elevation since it forms a bridge circuit with the potentiometer in the sight unit when the control box switch is set to GUNS.

PRINCIPLES OF OPERATION.—As pointed out previously, the control box contains a potentiometer and a switch. When the switch is on GUNS, the reticle is automatically positioned at zero sight line for use in air-to-air gunnery. When the switch is on MANUAL, the control box potentiometer is connected into the circuit so that the sight line can be offset to sight angles above or below the zero line by rotating the dial to the desired setting for air-to-ground operations.

The theory of operation of this circuit can be explained by referring to the simplified circuit shown in figure 4–38. For clarity on the simplified diagram a single relay with coil C has been substituted for an entire relay system from

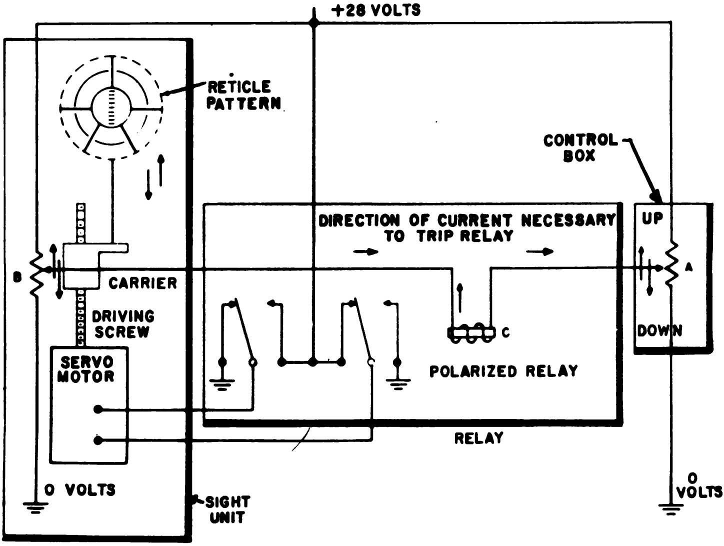


Figure 4–38.—Simplified circuit diagram.

the actual unit. The polarization is designated on the simplified diagram by making the assumption that current through coil C, only in the direction indicated by the arrows, will cause the relay to trip.

Moving the contact of potentiometer A DOWN will cause the sight line to be offset below the zero sight level, and in a like manner a movement UP will cause the sight line to be offset above the zero sight level. The servomotor (a high-speed, reversible, d-c motor) does the actual positioning. By applying torque to the driving screw, the motor winds the carrier up or down depending upon the direction of rotation. The fundamental purpose of the electrical circuit, therefore, is to control the direction of rotation of the motor.

Power is supplied to the motor by means of a polarized reversing (double-pole, double-throw) relay. (See fig. 4–38.) Assume the normal position of the relay is as shown. The relay armatures are held in this position by springs until a current through coil C produces a magnetic force that will throw them in the opposite direction. When this occurs, it will be noted that the polarity of the power input to the motor is reversed. This reversal in power input causes the motor to rotate in the opposite direction.

The current that actuates the relay results from a difference in potential between the sliding contacts of potentiometers A and B. Assume both contacts to be at the bottom of their respective potentiometer windings, DOWN position. There is no voltage difference between the sliding contacts; therefore, no current will flow through coil C. Move the sliding contact of potentiometer A to some midscale reading. This causes an increase in the potential of point A. Since B is still at the bottom and is now at a lower potential than A, current will flow from B to A through coil C. This trips the relay and the motor drives the reticle carrier UP, the screw carrying the reticle and the sliding contact of potentiometer B.

As the sliding contact of point B approaches the same potential as that of point A, the voltage difference decreases until they again reach the situation where the voltages at the sliding contacts are equal. Since they are at the same potential, current ceases to flow through coil C and the relay's contacts return to the position shown in the simplified diagram of figure 4–38.

With the switches in this position the motor reverses direction of rotation and drives the reticle carrier DOWN, again causing a voltage differential between the sliding contacts. The carrier does not travel far when the relay trips and the carrier returns toward the point of equal potential. The system oscillates, or hunts, about this point as long as it is in use.

When point A is moved DOWN to a position where the potential is below that of point B, the current flows from A to B through coil C. Since the relay is polarized, this current, opposite to the indicated direction of flow on the simplified diagram, does not activate the relay. Therefore, the relay stops oscillation in the position shown on the simplified diagram, is driven DOWN to the position selected on the control box, and begins to oscillate about this new point. In this way the servomotor positions the sight line by moving the reticle to any position selected by the operator. The electrical circuit is essentially a Wheatstone bridge circuit.

OPERATION.—Operation of Aircraft Sight System Mk 1 consists of energizing the lamps' circuit and then adjusting the rheostat to a comfortable illumination level. Next the controls on the control box should be set. The GUNS-MANUAL selector switch should be placed in the desired position, and the SIGHT ELEVATION MILS control should be turned to the needed preset detent position. These detents are set to standard sight angles as prescribed by squadron doctrine for the forthcoming operation.

MAINTENANCE.—The component units of the Aircraft Sight System Mk 1 are precision optical and electrical instruments and must be given due attention to insure that they are functioning properly when installed in operating aircraft. However, there are certain limitations placed upon the extent of the maintenance replacements and adjustments to be performed by squadron personnel. Equipment requiring maintenance that falls within the overhaul classification should be returned to overhaul shops for reconditioning. The manual for the equipments specifies the requirements for the different maintenance classifications.

For emphasis it is again pointed out that as Aviation Fire Control Technician 3, you are responsible for the performance of operational tests and external adjustments of these equipments; but the adjustments in the relay unit are essentially servo adjustments and are normally performed by AQ2. To aid you in making a preflight test the following procedure is recommended:

1. Close the power switches that connect the electrical supply to the system.

2. Note that the reticle image is visible on the reflector plate or the windshield. Rotate the dimmer rheostat knob through its operating range. The dimmer control should continuously vary the brilliance of the reticle image.

3. Set the filament-switch lever to the alternate position. The reticle image should still be visible.

4. Throw the GUNS-MANUAL switch lever on the con-

trol box to the GUNS position. The scale indicator on the sight unit should quickly aline to the zero index on the scale.

5. Set the switch lever on the control box to the MANUAL position and rotate the control dial to 30 mils UP. Check to see that the scale indicator on the sight unit indicates 30 mils above zero. The control dial and scale readings should agree within two mils.

6. Repeat step 5 using an UP 60-mil control dial setting.

7. Repeat step 5 and 6 using the same control dial settings in a DOWN direction. Each scale indicator reading should agree with the dial setting within plus or minus two mils.

8. The three detents in the control dial should be inspected and, if necessary, reset to the sight elevation mil values that will be used in the coming operation. Each detent can be set in the following manner:

a. Rotate the dial until the detent assembly is engaged in the detent.

b. Loosen the self-locking nut on the detent screw assembly.

c. Rotate the dial until the desired dial setting is directly below the index mark.

d. Tighten the self-locking nut to hold the detent screw assembly in place.

QUIZ

1. A body that is an original source of light is said to be
   - a. nonluminous
   - b. opaque
   - c. luminous
   - d. translucent
2. If a source of light actually reflects light from another source it is said to be
   - a. nonluminous
   - b. fluorescent
   - c. luminous
   - d. translucent
3. The approximate speed of light in space is ________________ miles per second.
   - a. 750,000
   - b. 100,000
   - c. 186,000
   - d. 3,000,000
4. A material that either reflects or absorbs all the light that strikes it is said to be
   - a. transparent
   - b. opaque
   - c. luminous
   - d. translucent
5. The angle of incidence is the angle between the incident ray and the
   - a. incident plane
   - b. reflected ray
   - c. surface
   - d. normal
6. A thin-edged lens is often called a ________________ lens.
   - a. positive
   - b. negative
   - c. concave
   - d. divergent

7. The changing of direction or bending of light rays as light travels from one medium to another of varying densities is
   a. reflection
   b. converging
   c. refraction
   d. diffusion
8. Light rays entering a denser medium tend to bend
   a. toward the normal
   b. away from the normal
   c. at the optical center
   d. away from the optical center
9. It is often necessary to change the light direction of the path in some optical instruments. The most satisfactory method of doing this is by using
   a. ducts
   b. lens
   c. channels
   d. prisms
10. The distance from the optical center of a lens to the focal point is the
    a. focal plane
    b. focal length
    c. optical plane
    d. optical length
11. What type of lens would be used to bend parallel light rays so that all the rays arrive at the same point?
    a. Concave
    b. Divergent
    c. Collimator
    d. Convex
12. The purpose of a collimating lens is to bend light rays until they are
    a. parallel
    b. convergent
    c. divergent
    d. perpendicular
13. The first sights used in aircraft gunnery were
    a. lead computing
    b. illuminated
    c. ring and bead
    d. telescope

14. The Mk 8 illuminated sight was designed for use with ________ guns.
    a. turret
    b. flexible
    c. free
    d. fixed

15. The Mk 18 gunsight is designed to be used with
    a. turret installations
    b. fixed gun installations
    c. free gun installations
    d. bombing installations

16. The major difference between the Mk 18 Mod 6 and the previous mods of the Mk 18 is that on the Mod 6 the ________ has been eliminated.
    a. fixed image
    b. mechanical ranging system
    c. stadiametric ranging
    d. lead-computing gyro

17. The Gunsight Mk 23 was adapted for use in fixed gunnery from the Gunsight
    a. Mk 6
    b. Mk 8
    c. Mk 9
    d. Mk 18

18. The AFCS Mk 16 can be adapted for use with various types of armament by changing the
    a. armament installation
    b. reflector plate
    c. ballistic plug-in elements
    d. type reticle

19. The Illuminated Sight Mk 20 differs from the Mk 8 in that the reticle is mounted on a turntable so the operator may select one of ________ different patterns.
    a. two
    b. three
    c. four
    d. five

20. The Illuminated Sight Mk 20 Mod 4 differs from the Mod 0 in that it has an adjustable
    a. masking lever
    b. range unit
    c. reflector plate
    d. gyro image

21. The movement of the movable image in the Sight Unit Mk 6 Mod 1 is accomplished by the use of servo units and a
    a. movable mirror
    b. gyro unit
    c. gunsight controller
    d. ranging throttle grip

22. Humidity control for the Sight Unit Mk 6 Mod 1 is provided by
    a. changing the silica gel
    b. forcing dry air into sight unit
    c. cockpit pressure system
    d. automatic dessicator unit

23. The three components of the Aircraft Sight System Mk 1 are
    a. relay, sight unit, and gunsight controller
    b. relay, sight unit, and control box
    c. sight unit, control box, and gunsight controller
    d. sight unit, control box, and ranging throttle grip

24. The reticle image is offset in the Aircraft Sight System Mk 1
    a. at the factory
    b. by adjusting the sight unit
    c. by adjusting the reflector plate
    d. by means of a servo unit

25. Adjustments in the relay unit of the Aircraft Sight System Mk 1 are normally performed by
    a. AQ2 or above
    b. O&R AQ personnel only
    c. factory representatives only
    d. any AQ available

CHAPTER 5

AIRCRAFT COMPUTING SIGHTS

Earlier in this course it was stated that there are two general classifications for describing fire control systems. These classifications amount essentially to distinguishing sights belonging either to the director system or to the disturbed system. Briefly, in a director system the operator (gunner or pilot) directly controls the sighting system (optical or radar). By maintaining the sight line on the target, its angular position is determined. This information is then fed to the computer which uses it to determine the proper lead and transmit this lead to the control system which in turn positions the gun. This movement of the guns can be accomplished by remotely controlling a turret or positioning a spot on a scope by maneuvering the aircraft. Displacement of this spot from the intersection of reference cross hairs indicates to the pilot in which direction he must maneuver his aircraft and thereby the guns. Note that the target dot is not actually the target but the point of aim computed from ballistic and flight information.

The second classification is the disturbed system. Briefly, in this system the operator (gunner or pilot) either manually or with the aid of a power mechanism exercises immediate control over the position of the gun (turret or aircraft). Information giving the instantaneous angular position and angular rate of the gun is then fed into the computer which uses it to compute the proper lead. This computer output then actuates a control mechanism which drives the line of sight into tracking position to effect the required lead angle. The important thing to notice here is that the pilot or gunner has only an indirect control over the line of sight. The name "disturbed sight" arises from the fact that a given motion of the aircraft or gun will, in general, produce a different motion of the line of sight.

In this chapter we shall consider a particular version of the disturbed sight known as the DISTURBED RETICLE SIGHT. This system is also known as a COMPUTING SIGHT. Further, we shall only consider the systems used for forward firing armament. Computing sights used in turret control will be discussed in a later chapter. This type of sight system essentially provides a line of sight by means of an illuminated reticle which is reflected by a movable mirror within the sight head onto a viewing glass fixed on the aircraft. The pilot moves the aircraft so as to keep the reticle image centered on the target and in so doing automatically displaces the line of sight from the direction of the gun bore by the proper lead. The range to the target, a continuously varying quantity, is obtained by one of two means—STADIAMETRIC RANGING or RADAR RANGING.

Whereas sights based on the director principle make the problem of tracking easier for the pilot, disturbed sights are, on the other hand, smaller, lighter, and simpler mechanically. These optical sight systems also have the advantage of being relatively free from electrical and electronic malfunctioning. Because these sight systems are utilized in the aiming of several types of armament they are called AIRCRAFT FIRE CONTROL SYSTEMS. We propose, then, to discuss the basic systems using the currently operating systems as typical examples.

AIRCRAFT FIRE CONTROL SYSTEMS MK 6

The Aircraft Fire Control Systems Mk 6 series are pilot-operated systems for use in attack and fighter type aircraft. They provide lead angle information for aiming various fixed, forward firing armament. The lead-computing mechanism is an electromagnetically controlled gyroscope housed within the sight unit.

The target is viewed by the pilot through a clear glass reflector plate on which are reflected two reticle images produced by two similar optical systems. The recticle images are focused at infinity which causes them to appear to be superimposed on the target. The fixed reticle image, seen by the left eye, establishes a fixed sight line which indicates the direction the aircraft and guns are pointing. The fixed reticle image is used as a standby or as a reference. (See fig. 5–1.) Either or both images may be illuminated by the pilot from a control box.

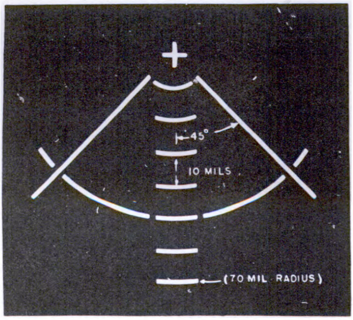


Figure 5–1.—Fixed reticle image pattern.

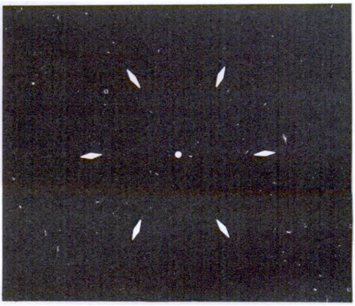


Figure 5–2.—Gyro reticle image pattern.

The gyro or movable image, seen by the right eye, is composed of six diamond-shaped dots with a round dot in the center. (See fig. 5–2.) This center pip of the image establishes a sight line which is automatically offset from the fixed sight line at the proper angle (lead angle) for hitting the target. Using this image, the pilot's problem is simplified to pointing the aircraft so that the dot of the reticle image remains on the target until the attack has been completed. However, for various types of attack the controls of each system must be set to agree with the type of armament used. The pilot makes this selection from the switch box of the system. Preliminary adjustments are also needed, but these are made at the time of installation and need not be changed by the pilot.

When this system is used with a radar for ranging, the diameter of the reticle image will automatically INCREASE as the range closes; that is, the six diamonds in figure 5–2 will travel away from the center dot.

When radar is not used, range is manually fed into the system by means of the ranging throttle grip shown in figure 5–3. In using the ranging throttle grip, the pilot first sets a span lever on the face of the sight unit to the estimated dimension of the aircraft which is being tracked. (Recall from chapter 3, this is stadiametric ranging.) Rotating the throttle grip varies the diameter of the reticle image. By keeping the target framed within an imaginary circle formed by the inside of the six diamond-shaped pips, proper instantaneous range is fed into the sight unit by triangulation.

Components and Functional Operation

At the present time there are four mods of Aircraft Fire Control System (AFCS) Mk 6 series (Mods 0 to 3 inclusive). Mods 0, 1, and 2 are quite similar; the differences in mod components being the result of the type of armanent used. The Mod 0 is used for the firing of rockets and either caliber .50 guns or 20-mm guns. Mod 1 is the same as Mod 0 with the exception of the rocket provisions. Mod 2 (fig. 5–3) is the same as the Mod 0 in that it is a two-purpose system used as a gunsight or as a rocket sight. It differs from Mod 0 in that both gun circuits are for 20-mm armament. In the Mk 6 series the gun circuit to be used is selected at the time of installation by a control located in the relay box and is not changed by the pilot. However, he can switch from rocket to guns in flight.

Mod 3 of this system is similar to the Mod 0 with exception of the stadiametric ranging provisions. Mod 3 differs in that it uses a magnetic amplifier range data converter in place of the gunsight controller and radar range servo. Also, it includes range limiting and an aural alert (firing tone). Because the Mod 3 is the latest in this series, a discussion of this mod will follow the discussion of the general system.

The AFCS Mk 6 series are lead pursuit systems for air-

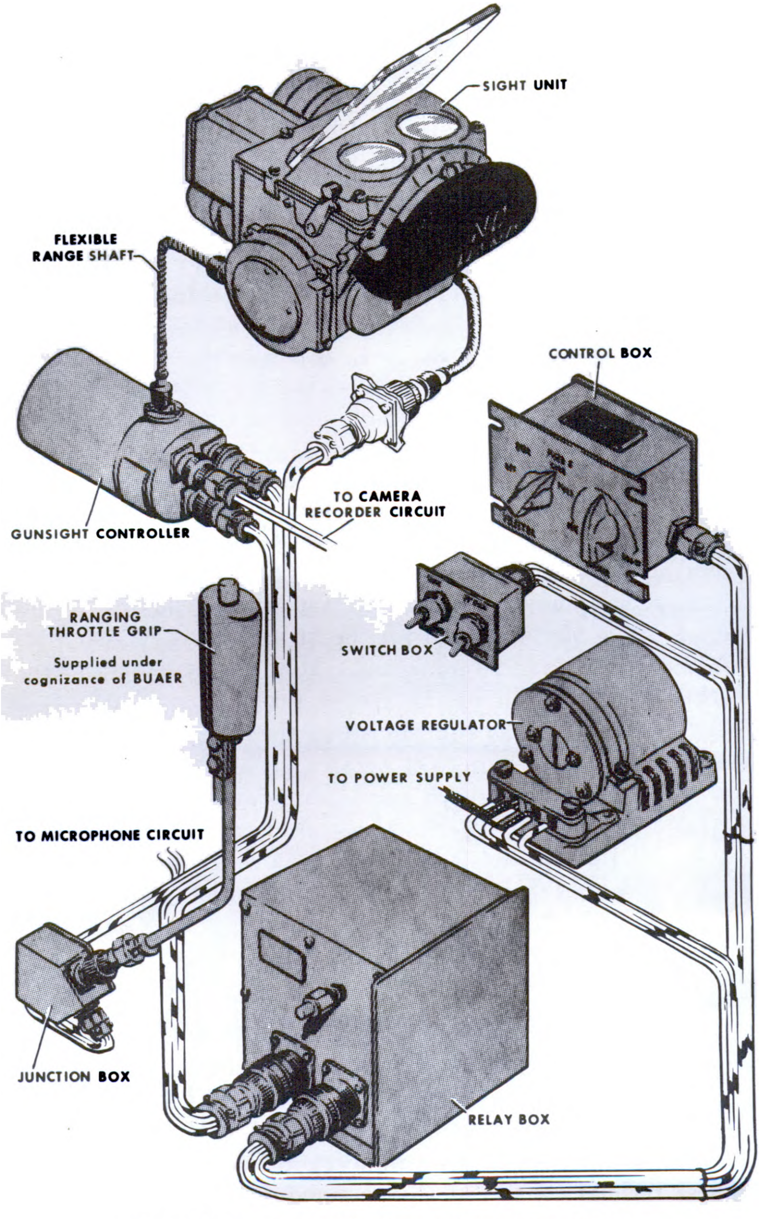


Figure 5–3.—Aircraft Fire Control System Mk 6 Mod 2.

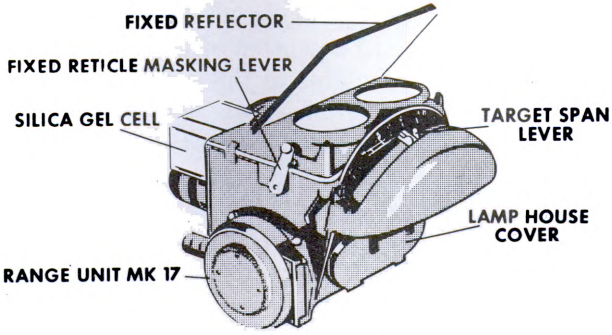
to-air gunnery. They also provide offsets for air-to-ground gunnery and rocketry with exception of the rocket provision in the Mod 2. In the versions of the series equipped with fixed reflector plate sights, offsets are put into the system electrically. The pilot decides between two dive angle conditions and sets the switch accordingly. Where the adjustable reflector plate is used, offsets are obtained by mechanically changing the angle of the reflector plate. These systems do NOT furnish gravity corrections.

The components used in the different mods of the Mk 6 series have themselves different mod numbers such as the sight units shown in figure 5-4. Each mod, of course, has its special considerations. It does not serve our purpose in this course to enter into a discussion of the various mods; therefore, our examination of the Mk 6 series will be concerned with the general operation and functioning of the components and the part each plays in the system. For the peculiarities of a specific mod, you are referred to the appropriate *Handbook of Service Instructions.*

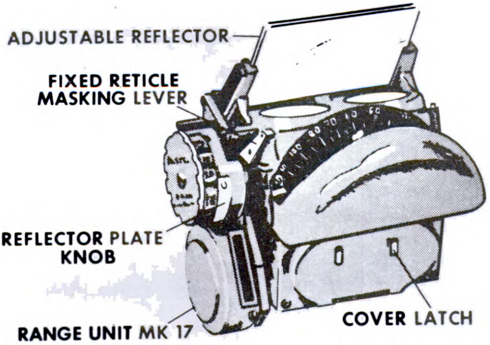
SIGHT UNIT.—The Sight Unit Mk 8, as shown in figure 5-4, is the heart of the system. It computes the head angle using the principle of a rate gyroscope, the deflection of the gyro being made proportional to the lead angle. A mirror mounted on this gyro deflects the path of the light from the target to the pilot's eye in such a way that when the pilot sees the target in his sight, his aircraft is pointed at the future position of the target. Since the axes of the guns are essentially parallel to the fixed sight, the guns will be offset from the target by the required lead angle.

NOTE: Do not be guilty of the common error of confusing the Sight Unit Mk 8 with the Illuminated Sight Mk 8. This confusion often arises because of the similarity in names and the use of the same mark number.

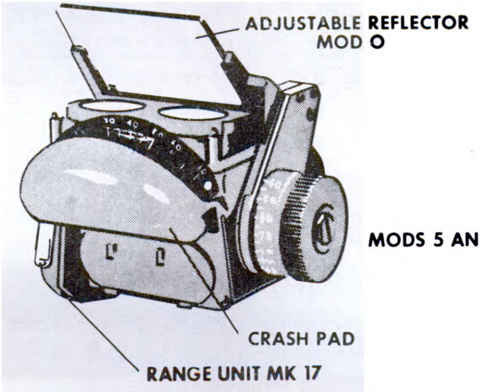
The OPTICAL SYSTEMS of the sight unit produce the fixed reticle image and the lead-computing or gyro reticle image by means of a light source mounted behind the reticles. These reticles consist of thin opaque disks containing geometrical openings which produce the desired image patterns.



MODS 0 AND 2



MOD 4



MODS 5 AND 6

Figure 5–4.—Sight Unit Mk 8 modifications.

The fixed reticle image uses one disk; the gyro reticle uses two metal disks mounted close together. These two gyro reticle disks are known as the span reticle and the range reticle disks. The span reticle disk has a pattern of six straight slits that radiate from a small hole in the center. The range reticle disk, located behind the span reticle disk, contains six spiral slits that radiate from a central hole. Since the two reticle disks are mounted concentrically on the axis of the optical system, the only points which pass light are the alined center holes of the two reticle disks and the points at which the straight and spiral slits intersect. (See fig. 5–5.) Thus, a circular image pattern of six equally spaced diamond-shaped pips with a round center pip is formed. The diameter of this circle can be varied by relative rotation of either reticle element. In order to prevent overlapping of the pattern, positive limit stops prevent rotation of either reticle beyond the maximum diameter position.

The gyro image is first reflected from a gyro mirror which is part of the gyro assembly. When the gyro mirror is positioned with its reflecting surface parallel to that of the

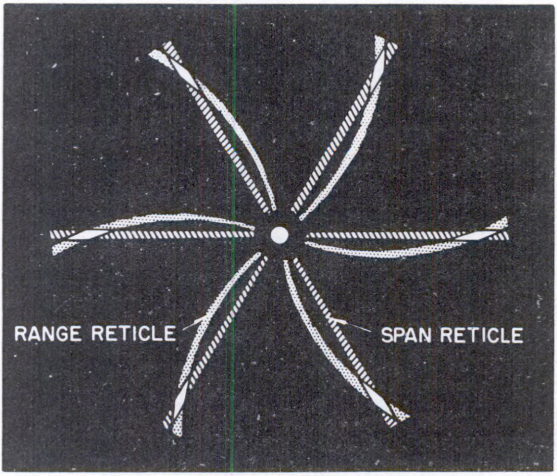


Figure 5–5.—Gyro reticle disks.

fixed mirror, the gyro image is reflected from the gyro mirror to the front mirror, through the collimating lens, to the reflector plate where it appears to be superimposed on the fixed image at infinity if both images have been selected by the pilot. If the gyro is tilted due to a turn of the aircraft, the gyro image reflection path is changed so that the gyro image is deflected to a new position, thus providing an offset line of sight which represents the lead angle. A simplified view of the optical system is shown in figure 5–6.

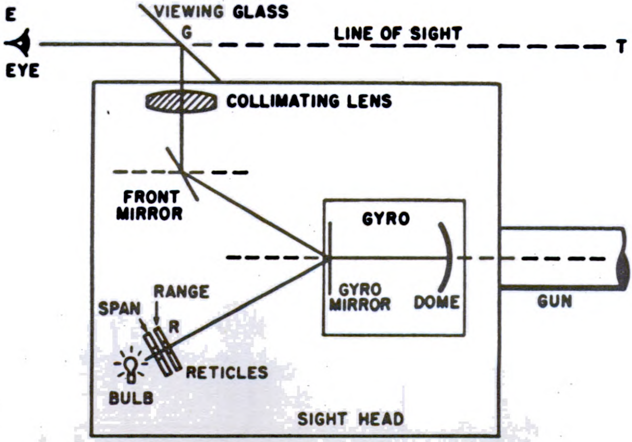


Figure 5–6.—Simplified view of optical system.

The span reticle is rotated by movement of the target span lever located in the front of the sight. The range reticle assembly is mechanically rotated by a gear train from the Mk 17 range unit which is located on the side of the sight unit.

The GYRO used in the sight unit differs from a conventional gyroscope in that its rotor is not a cylindrical disk but consists instead of a spin axle with a gyro mirror mounted on one end and a spherical aluminum dome or cap at the other. The spin axle is mounted on a Hooke's joint which allows the axle to be deflected in any direction.

A group of electromagnets is rigidly attached to the sight housing. The aluminum dome of the gyro passes through the

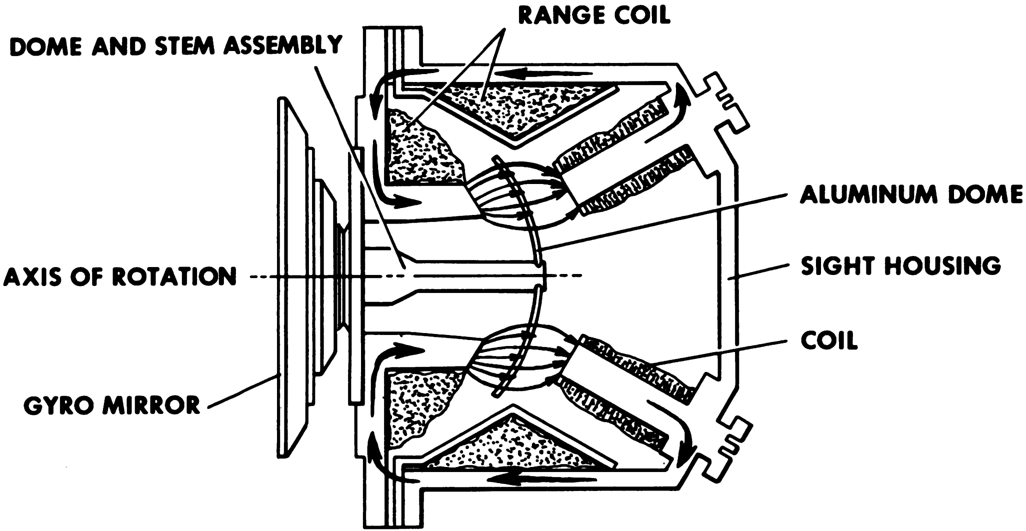


Figure 5–7.—Diagram showing gyro arrangement with a balanced flux path.

narrow air gap between the poles of these electromagnets. (See fig. 5–7.) As the dome spins in the magnetic field produced by these magnets, eddy currents are induced in the dome. (For a review of eddy currents, refer to *Basic Electricity*, NavPers 10086.) These eddy currents, in turn, react with the magnetic field to produce a mechanical force on the dome. This force tends to precess the dome toward the effective center of the magnetic field. The end result is the gyro assembly tends to aline itself so that the spin axis passes through the center of the magnetic field. When the pilot turns the aircraft so as to track the target, the gyro spin axis, in attempting to maintain its original position, lags behind the center of the magnetic field. This lag of the gyro axis causes the gyro mirror to tilt. The tilting of the gyro mirror causes the gyro reticle image to lag the image produced by the fixed reticle.

The deflection of the gyro image indicates the lead angle. (See fig. 5–8.) The amount of gyro lag depends upon the rate of turn (relative angular velocity of the target) and the strength of the magnetic field. Field strength is determined by the amount of current in the electromagnets. This current is supplied by a range and altitude control electrical resistance network which, in effect, makes the lag proportional to the bullet's time of flight. Thus the lead angle computed and indicated by the sight unit is equal to the angular velocity of the target with respect to the firing aircraft (determined by the aircraft's rate of turn) and the time of flight of the bullet. You will recall that the time of flight of the bullet is determined by the range and altitude. In other words, the lead angle is proportional to the product of the angular velocity and the range to the target.

The total effect of setting up the lead angle is to cause the gyro image to be deflected an amount equal to the lead angle in the opposite direction. The pilot, in order to keep the center pip of the gyro reticle pointed at the target, must turn his aircraft through an angle equal to the angle of lead. He thereby leads his target the right amount to get hits.

The Range Unit Mk 17 (figs. 5–3 and 5–4), which is a

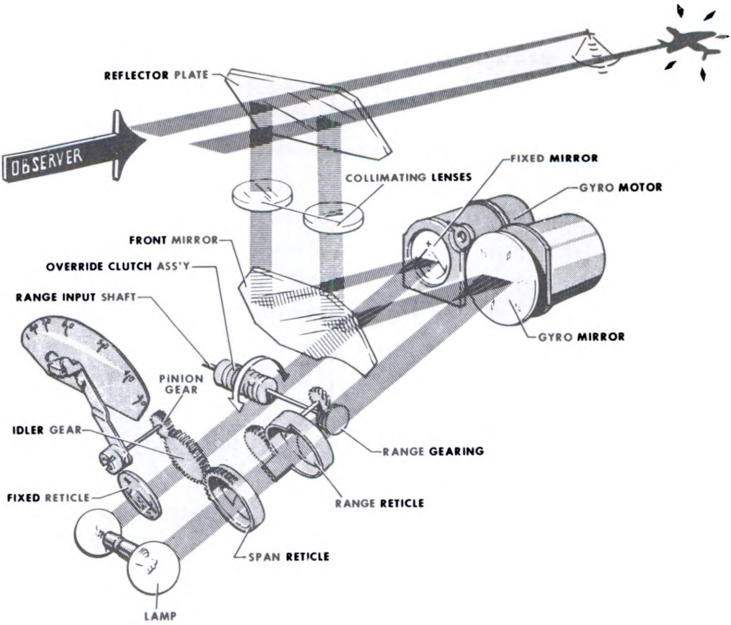


Figure 5–8.—Schematic diagram of optical system.

part of the sight unit, controls the lag of the gyro. This control is obtained by a variable resistance network which determines the amount of current flowing through the range coil. The current in the range coil, in turn, controls the strength of the electromagnetic field. Thus the current through the range coils and the lag of the gyros will be a function of range.

Gunsight controller.—The gunsight controller (fig. 5–3) is an electromechanical servo unit. The function of this unit is to drive the flexible range shaft connected to the range unit. The rotation of the flexible shaft varies the resistance in the range unit, which, in turn, controls the current through the range coils of the gyro. The gunsight controller will then drive the flexible shaft through an angle that depends on the position of the ranging throttle grip when employing manual operation. If automatic or radar operation is used, the gunsight controller is used in conjunction with a unit called a radar range servo. This unit automatically provides continuous range settings as determined by the radar.

Ranging throttle grip.—The ranging throttle grip (fig. 5–3) is used to furnish the basic range control, and also is used as an engine throttle control. By manual setting of the potentiometer contained in the ranging throttle grip, a voltage corresponding to the desired range is applied to the gunsight controller input. An electromechanical servo system in the gunsight controller turns the controller output shaft an amount corresponding to the desired range. As the ranging throttle grip is rotated, it will produce corresponding range changes in the setting of the controller shaft and the setting of the range unit. Thus, the range information and reticle size in the sight is controlled by positioning the range throttle grip. When the ranging throttle grip is set at the extreme maximum range position, the sight unit gyro is caged (highly restrained) to prevent tumbling of the gyro and blurring of the gyro image.

Relay box.—The relay box provides current limiting circuits which supply the range and elevation coils of the gyro with the proper amounts of current. Since the positions of the gyro and the gyro sight line are controlled by the coil currents, the relay box adapts the system for multipurpose use. The Mk 7 relay box is shown in figure 5–3.

The relay box also contains an **air density compensator unit**, which provides automatic corrections to the gyro sight line for trajectory variations caused by changes in air density with changes in altitude. The amount of correction supplied by this unit is proportional to the air density because, as the air density increases, the time of flight of the projectile increases and therefore the required lead angle increases. This compensator unit is a standard altimeter with a variable resistance which varies with altitude, hence inversely with air density. This resistance varies the current through the range coils, and so corrects the lead angle.

Control and switch boxes.—The control box (fig. 5–3) provides a means for energizing the electrical circuits of each system, for selecting the desired reticle image, and for controlling the intensity of the selected reticle images. The

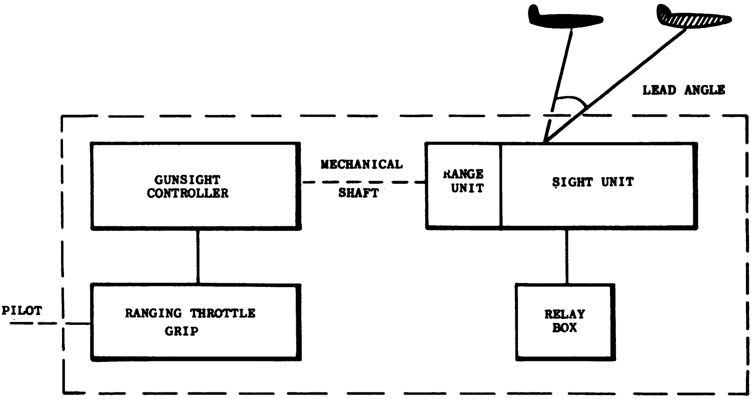


Figure 5–9.—Block diagram of AFCS Mk 6.

switch box selects gun circuits or rocket circuits. When rockets are selected, the switch box also selects dive angles of 35 degrees and over, or 35 degrees and under. The VOLTAGE REGULATOR is a carbon pile regulator designed to regulate the d-c input voltage to 22.0 ± 0.3 volts.

Let us summarize the functional operation of the AFCS Mk 6 series using the block diagram shown in figure 5–9. Range information is fed into the system by rotating the throttle grip. This range information is then transmitted through the gunsight controller to the range unit. This unit by controlling the current in the range coils determines the strength of the electromagnetic field. This field strength controls the deflection of the gyro and thus the gyro mirror. (See fig. 5–8.) Deflecting the gyro mirror changes the sighting position of the gyro images and thereby the lead angle.

Recall from chapter 3 that the lead angle is a function of the bullet's time of flight and the angular velocity of the target (rate of turn). Range in this system is determined by setting in the wingspan dimension by means of the target span lever on the sight unit. By knowing the wingspan, the distance to the reticle image, and the diameter of the reticle, range can be determined, as explained under Stadiametric Ranging in chapter 3. Now, by smoothly tracking the target, the range rate can be resolved. Also as the target is kept on the point of aim, any angular velocity of the target can be measured in the system by detecting own aircraft turning rate. This is accomplished by the gyro action.

With the inclusion of the necessary ballistics information (lost time of flight) from the relay unit, the fire control problem can be solved. Recall that:

$$\text{Time of flight} = \frac{\text{Range}}{\text{Muzzle velocity}} + \text{Lost time of flight}$$

Therefore, with angular velocity measured by the gyro and the information necessary for solution of time of flight available, lead angle can be determined. Lead angle is the product of angular velocity and the projectile's time of flight. NOTE: These systems do not furnish gravity corrections.

Operating Controls

The following controls, and their functions, are used in the operation of the AFCS Mk 6. Since the system is operated solely by the pilot, all controls are located in the pilot's cockpit. Although as an AQ3, you will not be operating the equipment in flight, you must be familiar with the controls to properly perform the preflight check as given in the maintenance section.

RANGING THROTTLE GRIP.—The ranging throttle grip is located on the engine throttle lever. As pointed out previously, it is used for varying the diameter of the gyro image to properly frame the target and thereby supplies the information needed to determine the lead angle. When the ranging throttle grip is turned to the maximum range condition, a limit switch is engaged. This causes a large amount of current to reach the gyro resulting in a caged (highly restrained) gyro. In rocket attacks, the ranging throttle grip is used only for caging and uncaging the gyro since ranging is not used. In rocket operation, the pilot should not attempt to "frame" the target.

TARGET SPAN LEVER.—The target span lever (fig. 5–4) is located on the sight unit. This span lever varies the diameter of the gyro reticle image. It must be preset to the known or estimated dimension of the target aircraft before correct range values may be obtained by the target spanning process in air-to-air gunnery.

FIXED RETICLE MASKING LEVER.—A fixed reticle masking lever (fig. 5–4) is also located on the sight unit. This control blanks out all of the FIXED reticle image except the cross when the lever is pushed forward. The fixed reticle masking lever is provided to eliminate the confusion of using both images together and yet enable the fixed cross to be used with the gyro reticle image for indications of lead.

SELECTOR SWITCH AND DIMMER CONTROL.—The selector switch and the dimmer control are located on the control box (fig. 5–3). The selector switch has four positions: OFF, GYRO, FIXED and GYRO, and FIXED. This switch turns the equipment on or off and selects the desired image(s). When the switch is in the GYRO or FIXED and GYRO position, the ranging servomechanism and the gyro lead-computing system are energized.

When the switch is in the FIXED position, only the fixed reticle image is visible, and the system is suitable only as a fixed reflector-type sight for estimating leads. The dimmer control varies the brightness of the gyro reticle image and/or the fixed reticle image for proper contrast with background light conditions.

ARMAMENT FIRE CONTROL SELECTOR SWITCH.—The circuit which is applicable to the respective armament is selected by means of the armament selector switch of the switch box (figs. 5–3 and 5–10). This switch box is used with AFCS Mk 6 Mods 0 and 2. Since the Mod 1 is a one-purpose sight system, a switch box is not used.

DIVE ANGLE SWITCH.—The dive angle switch (fig. 5–10) is used to select the dive condition to be used for rocket firing when the system is equipped with a fixed reflector plate sight. An offset is placed in the system electrically for each dive angle condition as indicated by the switch position. Dive angles are considered from horizontal flight. The offsets for the two dive angle conditions were harmonized at 25 and 42½ degrees, respectively. While optimum results are obtained at dive approaches near these dive angle conditions, accurate determination of the dive angle is not necessary for dives between 15 and 35 degrees and 35 to 60 degrees. For dives near 35 degrees, either setting will give satisfactory results. While the systems are set for dive angle conditions between 15 and 60 degrees, they may be used satisfactorily for conditions beyond these limits.

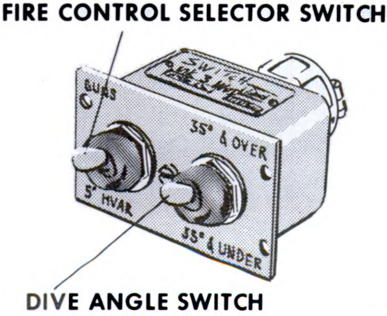


Figure 5–10.—Switch Box Mk 3 Mod 1.

Adjustable reflector plate.—The adjustable reflector plate (fig. 5–4) provides offset adjustments which are manually accessible to the pilot and provides greater offsets than are possible by electrical adjustments. The reflector plate is adjusted by means of a knob located on the side of the sight unit. When the sight is equipped with an adjustable reflector, the electrical offsets should be adjusted to equal zero from the boresight datum line for both high and low dive angles and for both the caged and uncaged condition.

Maintenance

Among the duties of an AQ3 are the following: Energize and secure aviation fire control equipment; set operating controls; make operator's adjustments; read and interpret dials; perform operational tests; make external adjustments; and isolate casualties to major component. (See Quals., appendix V.) Obviously to perform these duties, you have to know the correct operation of the equipment and be able to determine whether or not the equipment is performing correctly. As you know, or will find out, there is a world of knowledge between the person who can correctly turn ON a piece of equipment and the person who can ascertain the level of performance of that equipment. To aid you in the determination of the performance of the AFCS Mk 6 series, the following PREFLIGHT CHECK is recommended. Further, it is recommended that you study (not simply read) these steps for they will help you to a better understanding of the equipment.

1. Make sure all units are securely installed.
2. Examine all external cabling for frayed insulation, particularly where the cables enter connector plugs or cable clamps, or where they pass through bulkheads. Check all connector plugs to be sure that each is connected and drawn up securely on the receptacle.
3. Inspect the surfaces of the reflector plate, windshield, and top surface of the objective lenses. If these surfaces are dusty, they should be cleaned with a fine camel's-hair brush or by wiping lightly with lens tissue. If there are dirt streaks or smudges on the surfaces, they should be removed with a soft cloth moistened lightly. Do not rub hard or use harsh cleaners. Use white soap and water. The surfaces are polished and scratches will result from improper treatment. DO NOT TOUCH LENSES WITH FINGERS.
4. Inspect the color of the silica gel in the cell at the back of the sight unit (fig. 5–4). Dry silica gel is bright blue. If the color of the gel is not blue, replace the gel cell assembly with a replacement cell assembly from the spare parts set. If a replacement is not available, the gel may be dried by unscrewing the two filter plug assemblies, pouring the gel into a small metal container, and heating the gel at a temperature between 212° F. and 400° F. until it regains its original blue color. When the gel is dry, as evidenced by its bright blue color, its usefulness as a desiccant is restored and it can be replaced in the cell. Handle the gel particles as little as possible, in order to avoid crushing or crumbling. The ability of the gel to absorb is decreased if the particles are crushed.
5. Depress the two latches below the crash pad and open

the lamp cover. (See fig. 5–4.) Examine the two lamps. If either lamp shows signs of blackening, replace it with a new lamp. Care should be exercised in inserting new lamps so that the frosted spot on the lamp faces toward the reticle when the lamp cover is closed. Make sure the reflecting cavities and the glass window over the reticles are clean. Close the lamp cover, being careful to fasten the latches securely.

6. Check to see that the movement of the target span lever is free and without any trace of binding over the entire target span scale.

7. Swing the fixed reticle masking lever forward and back several times. The lever action should be smooth. A slight amount of spring drag should be present when the lever is near each of the stops. If any binding action of the lever is evident, the action may be eased by placing a drop of oil on the lever shaft at the point where it enters the sight unit housing.

8. Examine the flexible range shaft housing between the range unit and gunsight controller to be sure that there are no sharp bends or kinks in the housing. Check to see that each of the shaft couplings is tightened securely.

9. Rotate the SELECTOR switch to the FIXED and GYRO position—the gyro motor should start and both images should be visible on the reflector plate. The gyro image should stabilize quickly and be clearly defined. If the pips of the gyro image appear blurred and enlarged after an initial warmup period of five minutes, the gyro probably requires rebalancing and the entire sight unit should be replaced.

10. Rotate the DIMMER control from DIM to BRIGHT while observing the two reticle images. Note that the control varies the intensity of the images continuously over the entire range and that the light is evenly distributed over the reticle images.

11. Turn the SELECTOR switch to the FIXED position. The gyro image should disappear and the gyro motor should not run. The fixed image should be clearly defined.

12. Turn the SELECTOR switch to the GYRO position. The gyro reticle should become visible and the gyro motor should start. The fixed reticle should disappear. Return the SELECTOR switch to the FIXED and GYRO position.

13. With the fire control selector switch in GUNS position, check for parallax. Use the same procedure as given under the maintenance section for the Illuminated Sight Mk 8 with the exception that the permissible limit of image shift is THREE mils for the Sight Unit Mk 8.

14. Rotate the ranging throttle grip to its minimum range position. Note the diameter of the circle formed by the diamond-shaped pips of the gyro image, then rotate the ranging grip to maximum range position. Check the amount of travel on the scale and see that it is proportional to the rotation of the throttle grip.

15. Check the alinement of the fixed and gyro images. If the center pip of the gyro image does not coincide with the fixed cross, the fixed mirror needs adjustment.

16. Move the target span lever from right to left toward the higher setting of the span scale. The diamond-shaped pips should move out from the center pip of the gyro image.

17. Set the fire control selector switch in the 5″ HVAR position. This and the following steps are to check rocket sight controls and therefore do not apply to Mod 1.

18. Cage the gyro by rotating the ranging grip to maximum range position. Now, set the DIVE ANGLE switch to the 35° and UNDER position. The center pip of the gyro image should move to a position that corresponds to the rocket offset value required for dive angles between 15 and 35 degrees. The amount of offset can be gaged by using the 10-mil arc of the fixed image pattern.

19. Rotate the ranging grip so that the range dial indicates slightly under the maximum marked position to uncage the gyro. The gyro pip should remain at the same offset value as in step 18. A slight azimuth drift, not to exceed 7 mils, is permissible between caged and uncaged positions.

20. Set the DIVE ANGLE switch to the 35° and OVER position. The center pip should move to the rocket offset value required for dive angles between 35 and 60 degrees.

21. Cage the gyro. The pip should be located at the same offset value as in step 20. If the center pip does not move to the correct offset value in any of the three preceding steps and this step, the rocket offset adjustments need realinement.

Aircraft Fire Control System Mk 6 Mod 3

The AFCS Mk 6 Mod 3 is the latest in the Mk 6 series. It is quite similar to the previous modifications, and makes use of the same components as earlier versions of the Mk 6. The major change in the Mod 3 is the addition of certain equipment to provide for radar ranging. As in the earlier modification, stadiametric ranging can be utilized if desired or needed.

Another change to the Mod 3 is the provision of a tone circuit to indicate when the target is within firing range. The means of caging or uncaging the gyroscope at any time is also available, and an adjustable reflector is incorporated to permit the use of the system with different types of armament.

RADAR RANGING.—The equipment added to provide for radar ranging is the Range Data Converter Mk 31 Mod 0. This electronic device, which is connected with an AN/APG-30 radar set, plus components of the AFCS Mk 6 Mod 0 are used to create the AFCS Mk 6 Mod 3. NOTE: The AN/APG-30 radar set is not part of the AFCS Mk 6 Mod 3. When the range data converter is installed, all components of the Mk 6 Mod 0 are used except the sight unit, which is replaced by the Mk 8 Mod 9 sight unit. Also, the gunsight controller is eliminated.

The range data converter (fig. 5-11) receives from the radar a linear direct-current voltage which corresponds to range variations, and converts it into a nonlinear direct current which is modified for temperature and altitude variations. The modified direct current is then supplied directly to the range and elevation coils of the gyroscope. It is interesting to note that this modification of the direct current is obtained by the use of magnetic amplifiers. Although as an AQ3 you are not responsible for knowledge of the oper-

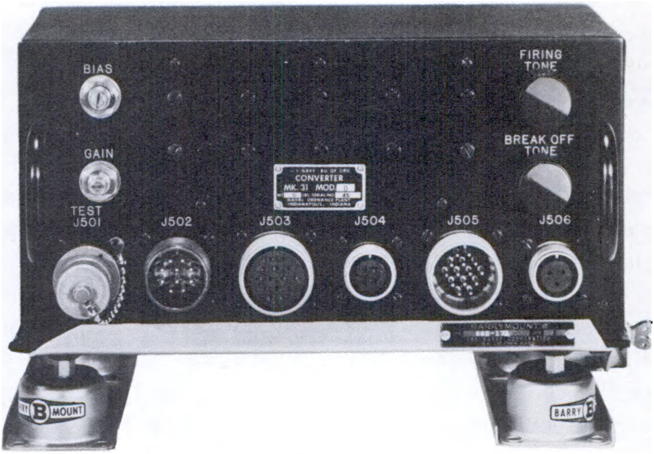


Figure 5–11.—Range Data Converter Mk 31.

ating principles of magnetic amplifiers, it will be to your benefit to know where and in what equipment they are utilized. With the proper range current supplied to the gyroscope, the sight unit will provide the proper lead for firing the guns in air-to-air operations.

The range data converter also contains a tone generator circuit. When the radar locks-on the target, this circuit generates a 400-cycle tone which is heard through the pilot's headphones. As the pilot tracks the target, range voltage decreases. At some preset value, which is equivalent to a preset range, the tone generator changes the tone to one of 800-cycles. This 800-cycle tone continues throughout the firing range. When the target range voltage reaches a second preset value (minimum range), the tone generator circuit is restored to its original condition causing the audio signal to change back to 400 cycles. This 400-cycle tone is the breakaway signal.

Stadiametric ranging.—Since the converter supplies the proper range current to the gyroscope, the use of this equipment does not require the pilot to set the estimated target dimension into the sight by means of the target span lever. However, provision is made for the pilot to set a fixed range current value into the sight unit by means of a manual ranging knob located on the left-hand side of the sight unit. (See fig. 5–12.)

To use the manual ranging knob, the radar switch must be set to the STANDBY-MANUAL or OFF position and the target span arm must be set to the known or estimated target dimension. Turning the manual range knob adjusts the diameter of the diamond-shaped pips to agree with that which is established for the usual stadiametric ranging problem. The manual range knob also positions the resistance potentiometer so that proper range current is supplied to the gyroscope for the selected fixed range. The firing range may then be estimated by using the diamond-shaped pips of the gyroscope reticle image. The tone alerting system does not function when operating manually.

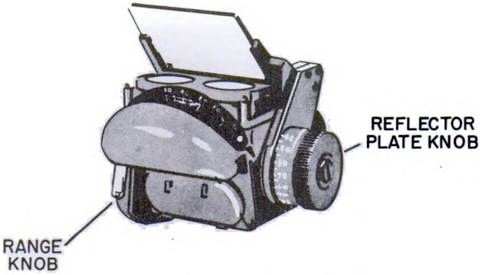


Figure 5–12.—Sight Unit Mk 8 Mod 9.

Caging the gyroscope.—Because the ranging throttle grip does not adjust the diameter of the pips as in other modifications of the Mk 6, it had to be modified for use in the Mod 3. The result is a grip that is used ONLY as a caging switch. By using this switch, the gyroscope may be caged or uncaged at any time.

Operation.—The AFCS Mk 6 Mod 3 is a versatile piece of equipment. It can be used for radar ranging for guns, manual ranging for guns, firing rockets, and bombing operations.

When using this equipment for radar ranging for guns, the radar is used to supply the range of the target. Once the radar has locked-on a target, the automatic alerting system will emit the 400-cycle note. The volume of the tone may be adjusted by the pilot. After target lock-on, the gyroscope should be uncaged and smooth tracking of the target commenced. The range data converter automatically and continuously supplies range data directly to the sight unit so that the proper lead is generated. When the firing range is entered, the tone should change to an 800-cycle tone and remain at 800 cycles throughout the firing range.

When using the Mod 3 for manual ranging for guns, the radar is not used. Range is determined stadiametrically. This is accomplished by setting the estimated target dimension in the sight by means of the target span lever. Then the fixed range for firing is set into the sight by the manual range knob which is located on the left-hand side of the sight unit. Finally, the gyroscope is uncaged, and tracking of the target with the gyroscope reticle image is started. At the proper estimated range, the firing is commenced. In this operation there is no continuous ranging of the target, and the aural tone alerting system does not operate.

The AFCS Mk 6 Mod 3 is also used for air-to-ground rocket firing. When used for this purpose, the radar is not put into use, and no ranging operation is necessary. The rocket circuit of Mod 3 is the same as the Mod 0 system. With the proper offset in the system and the armament switch in the proper position, the equipment computes the correct lead for firing rockets at stationary or moving ground targets. In addition to computing the lead, the system compensates for wind and target motion.

The rocket offset is called the "beta offset" and is defined as the amount that the gyroscope is depressed below the armament datum line for a negative offset, and raised above the armament datum line for a positive offset. This offset is expressed in mils and is primarily dependent upon the angle of attack of the aircraft's armament datum line, dive angle, speed, range to the target, type of rocket being fired and the rocket launcher angle. In the Mod 3 system, the proper offset for the armament is set into the equipment by the use of an adjustable reflector plate. The selection of the correct offset position is accomplished by the adjusting dial located on the right-hand side of the sight unit. (See fig. 5–12.)

When using the system for various bombing operations, the fixed reticle is used. The proper magnitude of bomb offset is set into the system by means of the offset adjustment knob. The Mod 3 equipment is used for bombing operations in conjunction with a bomb director. The computer of this bomb director establishes a tracking time, gives a signal when the pull-up should be started, and automatically energizes the release circuit at the proper instant in the pull-up so as to compensate for the effects of gravity on the projectile.

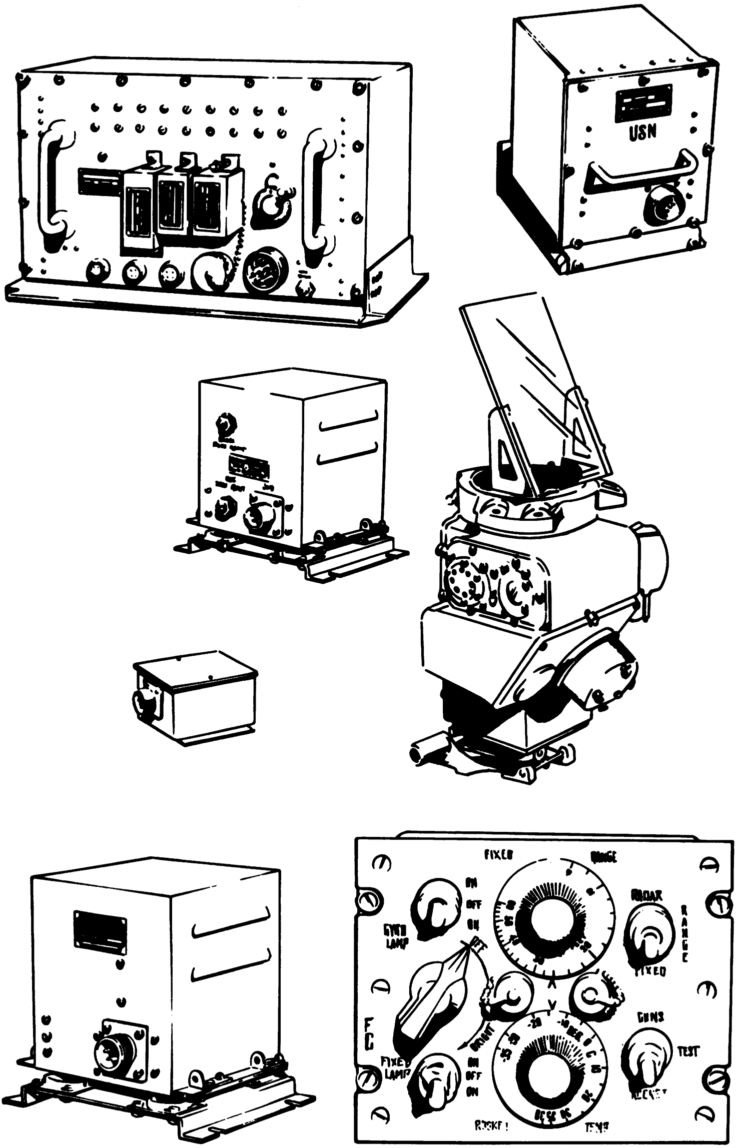
For a more detailed description and the theory of the bomb director and the Aircraft Fire Control System Mk 6 Mod 3, consult the appropriate *Handbooks of Service Instructions*.

AIRCRAFT FIRE CONTROL SYSTEMS MK 16

In considering the AFCS Mk 16 series, the same discussion procedure, as used for the Mk 6 series, is followed. The method is to discuss the components and how they are combined to form the system. Interest in mod numbers is secondary in nature and only referred to when necessary to the completion of the description. Operating controls and maintenance follows the section concerning the components and functional operation.

Components and Functional Operation

The AFCS Mk 16 series are electromagnetic and electromechanical computing devices used to aid pilots in aiming the guns and rockets of fighter aircraft in order to secure hits. Components of the Aircraft Fire Control System Mk 16 series are shown in figure 5–13. The system utilizes radar ranging, magnetic computers, and a gyro computing sight to present the point of aim to the pilot. This point of aim is indicated by a gyro reticle image called the pipper, and is accurately computed for service types of guns and rockets in air-to-air and air-to-ground maneuvers.



Computer Mk 86; Voltage Regulator Mk 14; Computer Mk 87; Sight Unit Mk 11 Mod 1; Power Supply Mk 75; Range Unit Mk 25; Control Box Mk 35 Mod 1.

Figure 5–13.—Aircraft Fire Control System Mk 16.

The Mk 16 series features simplified pilot's operation, with all inputs automatically fed into the system. Since the operation of the system during a firing run consists only of operating a caging switch (located on the throttle grip) and closing the firing switch, the pilot is free to concentrate on smoothly tracking the target.

A ranging tone informs the pilot when the target is within firing range in the air-to-air mode. The firing range is set in by a range dial and is adjustable in flight for both gun and rocket modes. Another feature of this system is that it compensates for the effects of gravity.

During the approach to the target, the gyro in the sight unit is caged to keep it from tumbling. The sequence of operation is shown in figure 5–14. The pilot then begins a pursuit course, estimates the target lead, and maneuvers the aircraft to lead the target accordingly, using the gyro pipper as a reference. The gyro is then uncaged and the pipper moves onto the target and remains there, assuming that a correct estimated lead angle was established with the gyro caged. The pilot makes the necessary flight corrections to keep the pipper on the target during the entire tracking run. As the aircraft closes in on the target, a ranging tone signal will be heard in the headphones. This tone signal informs the pilot that the aircraft is within the preselected firing range of the target. While the pilot concentrates on the smooth tracking of the target, the system continuously corrects the sight line to the proper angle necessary to score a hit. The fighter aircraft is maintained in a correct firing attitude during the time the ranging tone is on, provided the pilot tracks the target smoothly.

The ballistic constants required by the computer circuits for the particular bullets or rockets to be used are supplied by inserting suitable plug-in ballistic elements into sockets on the front of Computer Mk 86. There is a separate plug-in element for each type of gun and for each type of rocket to be used. Only one type of gun and one type of rocket can be used with the system on any one flight.

SIGHT UNITS.—The AFCS Mk 16 utilizes either Sight Unit Mk 8 Mod 8 or Sight Unit Mk 11, depending upon the par-

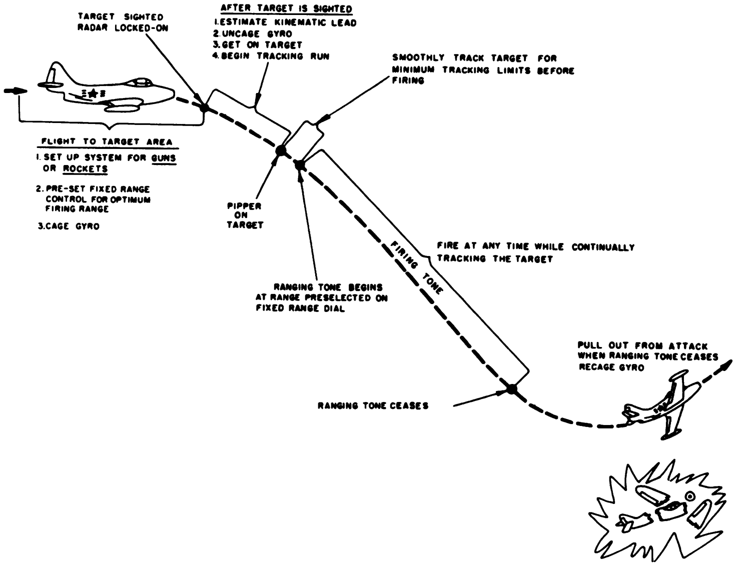

TARGET SIGHTED
RADAR LOCKED-ON
AFTER TARGET IS SIGHTED
1. ESTIMATE KINEMATIC LEAD
2. UNCAGE GYRO
3. GET ON TARGET
4. BEGIN TRACKING RUN
SMOOTHLY TRACK TARGET FOR MINIMUM TRACKING LIMITS BEFORE FIRING
FLIGHT TO TARGET AREA
1. SET UP SYSTEM FOR GUNS OR ROCKETS
2. PRE-SET FIXED RANGE CONTROL FOR OPTIMUM FIRING RANGE
3. CAGE GYRO
PIPPER ON TARGET
FIRING TONE
FIRE AT ANY TIME WHILE CONTINUALLY TRACKING THE TARGET
RANGING TONE BEGINS AT RANGE PRESELECTED ON FIXED RANGE DIAL
PULL OUT FROM ATTACK WHEN RANGING TONE CEASES
RECAGE GYRO
RANGING TONE CEASES

Figure 5–14.—Air-to-air attack cycle.

ticular aircraft installation. Note that the early mods of the Mk 8 sight unit are not used because the throttle grip serves only as a switch. These sights, the Mk 8 and Mk 11, function in the same manner but differ in physical construction. The differences between the two sight units are in appearance, size, and internal optics. Sight Unit Mk 11 utilizes a single collimating lens principle known as the monocular type sight. (See fig. 5–16.) With no lead angle, the projected images (fixed and gyro) appear to be superimposed when viewed with either or both eyes. Sight Unit Mk 8 Mod 8 utilizes dual collimating lenses based on the binocular principle; this method projects two separate images on the reflector plate of the sight and they appear coincident only when viewed with both eyes. For a fuller description of the Mk 8 sight unit, you are referred to the preceding section on the AFCS Mk 6 series.

The function of the sight unit is to indicate the point of aim (total lead angle) to the pilot. This is accomplished by a movable pipper positioned according to the turning rate

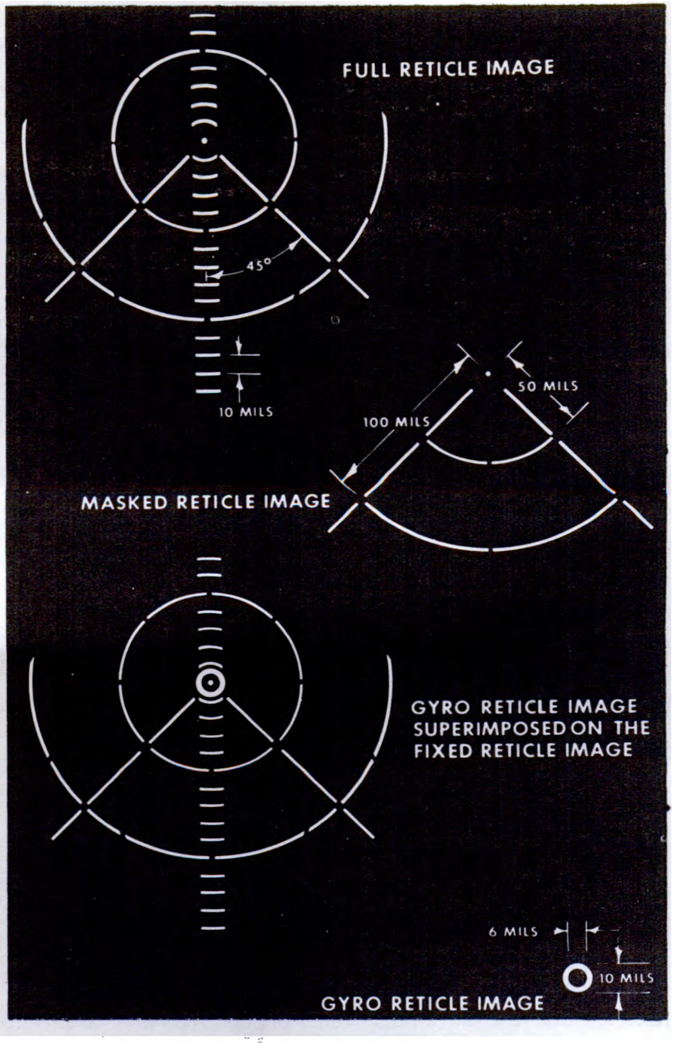


Figure 5-15.—Sight Unit Mk 11 reticle images.

of the aircraft and the information received from Computer Mk 86.

The Sight Unit Mk 11 (fig. 5–13) houses the lamps and optics, which form the reticle images, and a rate measuring element—the gyro. There are two images produced by the sight unit—the fixed reticle image which is boresighted with the guns and always indicates the gun line, and the gyro reticle image, or pipper, which is a doughnut-shaped image used for sighting on the target. (See fig. 5–15.) The position of the pipper depends upon four things: The rate at which the aircraft changes direction plus three electrical currents (range, elevation, and azimuth) fed into the sight unit.

The gyro unit contains a motor driven gyroscope which is merely a mirror assembly spinning at high speed. The gyro tends to remain pointing in a fixed direction. It is mounted by use of a universal joint (Hooke's joint) arrangement so that it is free to tilt in any direction. Thus, when the aircraft turns, the sight unit also turns around the gyro and the gyro tends to remain pointing in the original direction. As shown in figure 5–16, a mirrored surface (which is a part of the gyro) reflects the pipper image to the reflector plate so that the pipper indicates the direction in which the gyro is pointing.

The gyro dome spins in the magnetic field set by the range, elevation, and azimuth currents flowing through the irrespective coils. The dome spinning in the magnetic field causes eddy currents to flow within the dome. When the sight unit is turned around the gyro dome and mirror, the center of the magnetic field is moved with respect to the gyro dome. As the center of the magnetic field moves away from the center of the gyro dome, precession forces due to the eddy currents within the dome cause its center to seek the center of the magnetic field.

The amount of precession which takes place depends on the rate of turn of the aircraft and the magnitude of the currents flowing through the range, azimuth, and elevation coils. The result is that the gyro will follow, but will lag behind, the movement of the aircraft. The gyro reticle image will

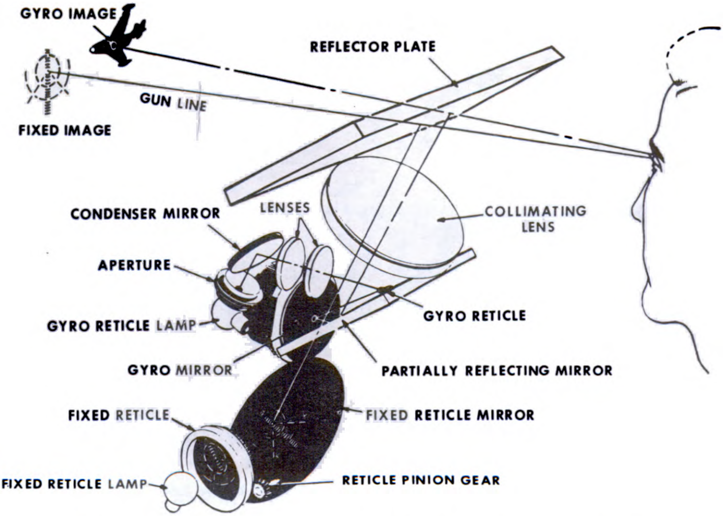


Figure 5–16.—Schematic diagram of optical section of sight unit.

also lag behind the fixed reticle image. The angular displacement of the gyro reticle image from the fixed reticle image will equal the total lead angle required for a particular attack run.

If the range to the target is very long, the range current will be small and the force pulling the gyro in line with the aircraft will be small, while the gyro lag and the indicated lead angle will be large. If the range is short and the turning rate of the aircraft is the same as before, the range current will be large and the indicated lead angle small. The magnitude of the range current is determined by Computer Mk 86.

Besides the kinematic lead just discussed, there are additional factors requiring compensation. In the AFCS Mk 16 series, the sight is automatically adjusted to compensate for gravity by the elevation current. This current flows through two elevation coils in the gyro in such a way as to change the effective center of the range electromagnet. The gravity correction causes the gyro to be offset downward.

Kinematic lead is now generated with respect to this new "zero" point.

In addition to gravity drop, the elevation current, which is produced in Computer Mk 86, compensates for other factors such as angle of attack and rocket-launcher angle.

When firing rockets, it is also necessary to compensate for the angle of skid. This is the angle in aircraft's lateral plane between the rocket-launcher line and the aircraft's flight path. (See fig. 5–17.) Compensation is accomplished by causing the pipper to be offset to the right or to the left by means of azimuth current from Computer Mk 86 flowing through two azimuth coils. These coils produce the same effect as the elevation coils, except that the pipper moves in azimuth rather than in elevation.

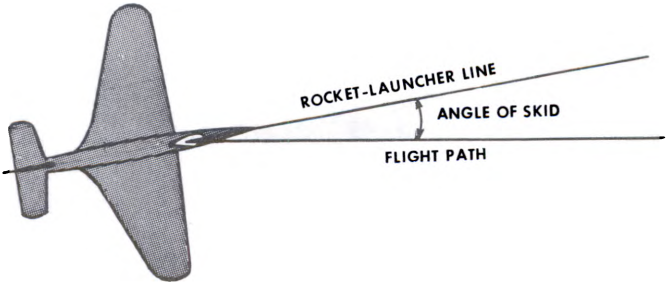


Figure 5–17.—Angle of skid.

To summarize, the elevation coils move the pipper up and down and the azimuth coils move the pipper to the right and left to compensate for variables such as gravity drop, attack and skid angle, and so forth. These coils cause the pipper to be offset to a point about which the kinematic lead is generated. The kinematic lead is generated along the line of relative motion of the target.

Computer Mk 86.—The purpose of the entire Aircraft Fire Control System Mk 16 is to position the pipper in the sight unit. It has been shown that the pipper position depends upon the rate of turning of the sight, and upon the range, elevation, and azimuth currents which are produced in Computer Mk 86. This computer (fig. 5–13) may be compared to a slide rule or a calculating machine in that it solves mathematical problems. Essentially, the computer is the brains of the entire system. However, the factors of the problem are fed into it automatically; the only things the pilot must do to operate the system are to turn on the power, operate the caging switch, and track the target smoothly.

Computer Mk 86 is different from the mechanical or vacuum tube computers used heretofore in that it employs a device called a magnetic amplifier. The magnetic amplifier has recently been adapted to perform many of the functions formerly performed by vacuum tubes, with a great reduction in the amount of maintenance required. The magnetic amplifier is quite similar to a transformer in construction. As an AQ3, you normally will not be responsible for the maintenance of "Mag. Amps."

The BASIC COMPUTING ELEMENT of Computer Mk 86 is the phase-balance computer or PBC as it is commonly called. It is a plug-in unit composed of magnetic amplifier circuits. It has three inputs and one output. Quantities applied to two of the inputs are multiplied, and quantities applied to the third act as divisors. The output is equal to the product of the first two inputs divided by the third input. When the PBC is connected in another manner, it can also square and extract square root.

One of the things that the computer must solve for is RANGE CURRENT, the current used in the sight unit to control the generation of kinematic lead. This current depends upon the time required for the projectile to reach the target. You will recall that the fundamental factors necessary in calculating the TIME OF FLIGHT of the projectile are present range, range rate, and average velocity of the projectile. A range voltage directly proportional to target range is applied from the radar. The range rate is obtained from the other computer (the Mk 87) which produces an ouput voltage proportional to range rate, or rate of closing on the target.

The AVERAGE VELOCITY of the projectile is calculated in Computer Mk 86 from the following information: (1) aircraft velocity, supplied by an aircraft velocity switch in the computer; (2) air density, supplied by a pressure transmitter in the computer; and (3) projectile ballistics, supplied by plug-in units (fig. 5–18) on the front of the computer.

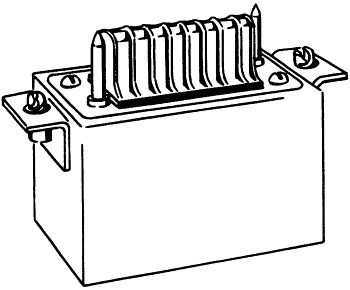


Figure 5–18.—Ballistic plug-in unit.

The above factors are supplied to the computer circuits and are used to calculate the value of range current, which is supplied to the sight unit. The ELEVATION CURRENT is computed by calculating gravity drop and then modifying it according to several variables. Information calculated in the range circuits is used to calculate the projectile drop due to gravity. This quantity is altered by the following factors:

1. When the aircraft is in a bank, the ACCELEROMETER in Computer Mk 86, together with a factor in the kinematic lead calculations, causes the gravity offset to be in a true vertical direction even though the elevation coils, in which the gravity correction current flows, are not vertical. The accelerometer consists of a weight connected to a variable resistance, mounted so that it responds to changes in force on the aircraft. Just as a person is pulled to one side of a speeding automobile as it rounds a curve, the accelerometer weight is moved as the aircraft turns. Since the aircraft is in a bank, the weight is pulled in a direction perpendicular to the aircraft wings. The distance of travel of the weight is a measure of the bank angle of the aircraft.

2. An ANGLE OF ATTACK and SKID COMPENSATOR adjusts the elevation output according to the direction of the airstream

past the aircraft. This is necessary to compensate for the fact that a rocket will turn into the airstream when it is released from its launcher. NEITHER of these factors enter into the gunfiring operation of the system. (See fig. 5–19.)

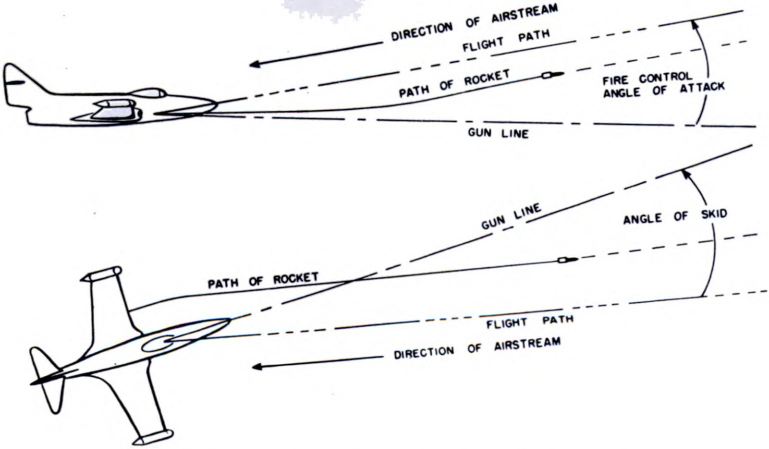


Figure 5–19.—Fin-stabilized rocket turns into flight path.

3. A launcher-angle control, mounted on the front of the computer can be adjusted to account for the angle at which the launcher holds the rockets. (See fig. 5–13.)

4. The ELEVATION CURRENT, computed from the above information, will cause the pipper to be offset in elevation the proper amount to score a hit.

5. The AZIMUTH CURRENT is computed from information calculated in the range circuits, and from information supplied by the angle of attack and skid compensator. This current will offset the pipper in azimuth when the system is set on rockets. For gun setting, this offset is zero.

COMPUTER MK 87.—The Computer Mk 87 (fig. 5–13) receives range information from the radar and uses that information to produce a d-c voltage proportional to the rate of approach (range rate or closing velocity) to the target. The computer consists of four electron tubes and other common electronic circuit components.

RANGE UNIT MK 25.—The purpose of the Range Unit Mk 25, shown in figure 5–13, is to make the pipper more controllable in getting on target, to produce a ranging tone, to indicate that the target is within the preselected range and to indicate the breakaway point. The range unit consists of thyratron tubes and transformer rectifier circuits.

During a typical tracking run, the fire control system is set for radar ranging. However, at long ranges the range unit causes the sytem to be in the fixed ranging condition. This enables the system to compute according to the value set on the dial on the control box, resulting in a more constrained pipper than would be normal while tracking a target at long range, thereby simplifying tracking maneuvers.

When the target range equals the value set on the FIXED RANGE dial on the control box, the fire control system is automatically switched out of the fixed range condition, and radar ranging begins. At the same instant, a ranging tone is applied to the pilot's headphones. This tone indicates that the target is within the preselected firing range set in by the pilot.

When the target range decreases to another preset range, the ranging tone ceases, warning the pilot that he should begin his breakaway. At the same instant the fire control system is again automatically switched to the fixed range condition.

AIRFLOW COMPENSATOR AND BALLISTIC ELEMENTS.—These units which plug into the front panel of Computer Mk 86 provide a means for adapting the fire control system to the desired type of gun or rocket and to the particular aircraft. (See fig. 5–18.) In any installation this gun and/or rocket ballistic element must be appropriate for the type of gun or rocket being used. The airflow compensator must correspond to the type of aircraft in which the system is installed.

CONTROL BOXES.—Several different control boxes are used with the AFCS Mk 16 series: Control Box Mk 35 (figs. 5–13 and 5–22); Control Box Mk 43 (fig. 5–20); and Control Box Mk 46 (fig. 5–23). All of the system controls, with the exception of the caging switch and fixed reticle masking control

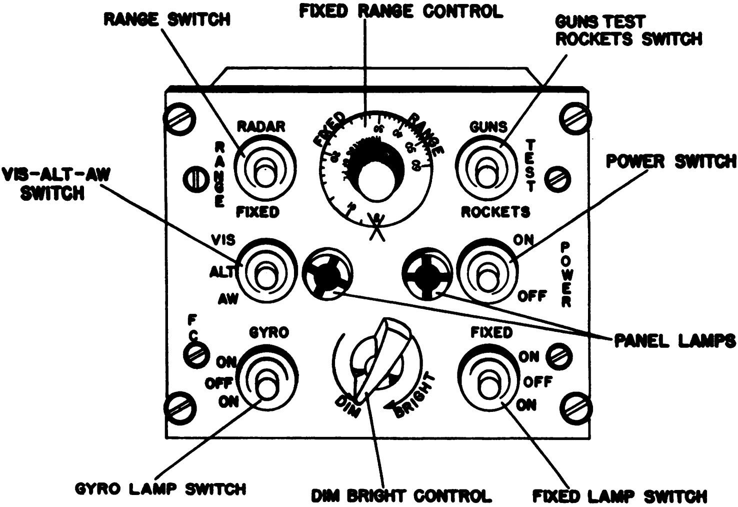


Figure 5–20.—Control Box Mk 43 Mod 0.

are located on the control box. In some installations of the fire control system a control box is not used, and the controls are relocated in a centralized fire control panel by the aircraft manufacturer. However, the controls are similar and serve the same purpose as those in the control box. The function of the controls will be discussed in the following section on operating controls.

Power Supply Mk 75.—Power Supply Mk 75 (fig. 5–13) furnishes d-c power to the sight unit gyro motor. It operates from a 3-phase, 400-cycle voltage source. The modification designation used depends upon the 3-phase inverter furnished with the aircraft.

Voltage regulator.—The Voltage Regulator Mk 14 Mod 0 provides a closely regulated a-c voltage to the sight unit reticle lamps. (See fig. 5–13.) It is used in conjunction with some mods of the Mk 35 control box. The OFF-BRIGHT control on the control box varies the output of the voltage regulator and therefore increases or decreases the brightness of the reticle images.

Illumination Transformer Mk 22.—The Illumination Transformer Mk 22 is used in place of the Voltage Regulator Mk 14 in some installations of the system. It is used with Control Box Mk 35 Mod 2 to supply the voltages to control the brightness of the sight unit reticle images. The illumination transformer is a tapped autotransformer, which supplies seven different voltages. The OFF-BRIGHT control provides a switching arrangement so that any one of the seven voltages may be selected to control the brightness of the reticle images.

AUXILIARY EQUIPMENT.—In order for the AFCS Mk 16 series to fulfill the purpose for which it has been designed, the following auxiliary equipment is required: (1) An automatic ranging radar, such as the AN/APG–30, is required for ranging information. Other radar sets may be used in conjunction with the system provided they supply the proper range voltage and output impedance. (2) An inverter is required to supply 3-phase power to the system. (3) Angle of attack and skid compensator, when the system is used for launching rockets, is required to furnish the necessary information to the computer. (4) Throttle grip caging switch is normally supplied as part of the aircraft. The cage-uncage switch is built into the grip.

SUMMARY.—Let us now summarize the functional operation of the AFCS Mk 16 series using the block diagram shown in figure 5–21. Range information is fed into the system from the radar to both computers. The Computer Mk 87 determines the range rate and feeds this to the Computer Mk 86.

With this and other necessary input information, including the gyro dome temperature from the sight unit, the computer calculates the currents for the sight unit gyro coils so that the gyro can perform its computation of the correct lead angle. As shown in figure 5–21, the currents from the computer to the sight unit are (1) range coil current, (2) elevation coil current, and (3) azimuth coil current. The sight unit incorporates this information from the computer with the kinematic information. The result is the production of the correct lead angle by the sight unit.

Besides the outputs to the sight unit, the computer also feeds a voltage proportional to the radar range to the range

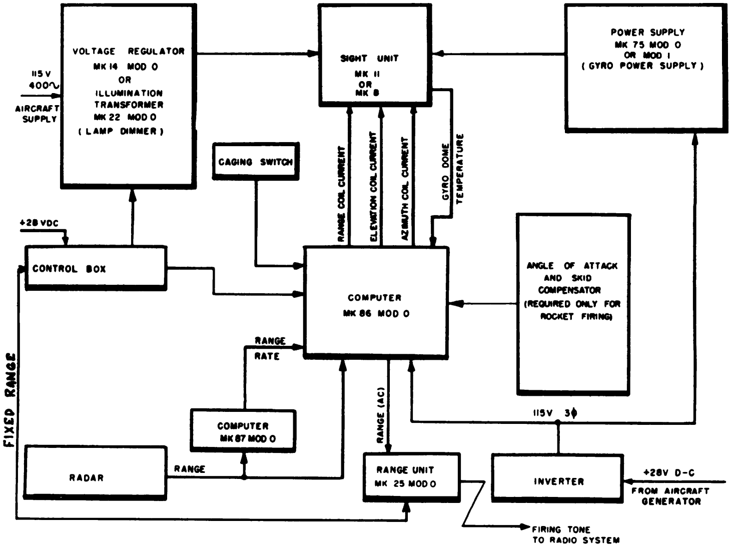


Figure 5–21.—Block diagram for AFCS Mk 16.

unit. The amplitude of this voltage is then compared to the voltage determined by the FIXED RANGE dial. The range unit provides for simplified tracking and tone when the target is within a preselected range. The range unit also signals the pilot when pullout should be initiated.

Operating Controls

All the controls of the AFCS Mk 16 with exception of the cage-uncage switch and the fixed reticle masking switch are on the control box. As pointed out previously, there are several different control boxes—the Mk 35, the Mk 43, and the Mk 46. Further, Mods 1, 2, and 3 of Control Box Mk 35 are in use. Each of the boxes is functionally similar; however, there is a physical difference in the location of the various knobs and switches. A visual inspection of the system will determine the type of control box installed in the aircraft. Certain installations of the fire control system do not use a standard control box, but have controls relocated in a centralized fire control panel. However, the function of the controls are similar to those in the control box.

Our purpose is to discuss the controls and their function as used in the operation of the Mk 16 series. Once again, as an AQ3, your interest in the controls lies in your responsibility to energize and secure aviation fire control equipment; set operating controls; and make operator's adjustments. (See Quals 101.2.)

CAGING SWITCH.—The caging switch is usually located on the aircraft throttle grip and is operated by rotating the grip. The switch has two positions, and its purpose is to tightly constrain the gyroscope in the sight unit. When the switch is in one position, the gyro is caged; when in the other position, the gyro is uncaged.

The switch is placed in the CAGE position at the time the system is energized so that the gyro pipper will be constrained and remain near the center of the fixed image during the flight to the target area, and while the aircraft is being maneuvered to get into a tracking position. The reason for caging the gyro is to prevent it from tumbling when the approach angle is too large or when the aircraft is pulling a large number of *g*'s.

The tumbling action occurs when the gyro strikes a bumper at maximum lead angles or pip deflections. This causes the pipper to become blurred in appearance and to move erratically about the reflector plate often becoming obscured from view. Such a condition would require the pilot to wait for the pipper to stabilize before getting on a target. In other words, the lead-computing properties of the sight unit are of no value while the gyro is tumbling.

After the aircraft is placed in a tracking position, the caging switch is placed in the UNCAGE position so that the gyro pipper can be alined on the target and thereby enable the system to compute the required point of aim for tracking and firing.

MASKING CONTROL.—The fixed reticle masking control is used to obtain variations of the fixed image pattern by positioning a reticle control. This control is usually located on the control panel of the aircraft. The exact location of the control will vary with the different types of aircraft using

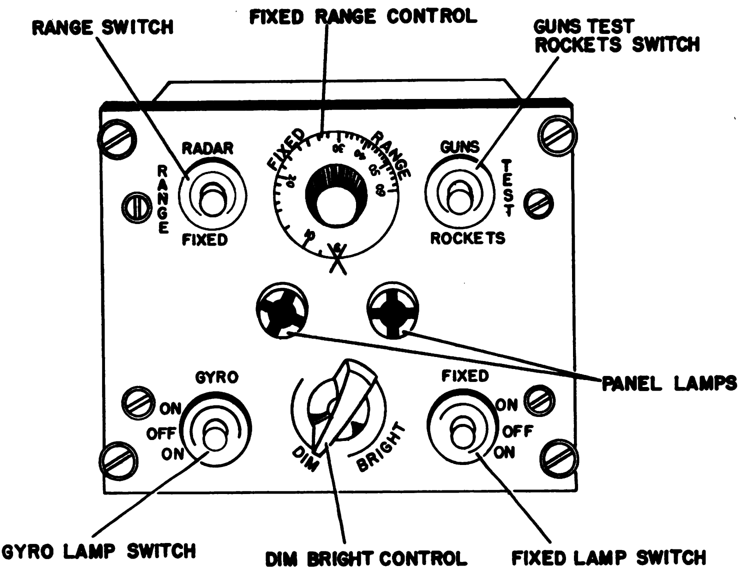


Figure 5–22.—Control Box Mk 35 Mod 2.

the fire control system. For a view of an unmasked and a fully masked reticle image see figure 5–15.

OFF-BRIGHT CONTROL.—The OFF-BRIGHT control (fig. 5–22) used on Control Box Mk 35 performs two functions. It serves as a master switch for turning on the power to the fire control system, and as a dimmer control to vary the light intensity of the gyro and fixed images. This control operates in conjunction with the GYRO LAMP and FIXED LAMP switches which must be in their ON positions to fully energize the system. When the OFF-BRIGHT control is in the OFF position, the system is completely de-energized. Rotating the control clockwise, approximately one-eighth turn, applies power to the system. Further clockwise rotation of the control causes the reticle image to become brighter, permitting adjustment of the image brightness to suit the light conditions. On the Control Box Mk 43, this control is replaced by the POWER SWITCH and the DIM-BRIGHT control.

GYRO LAMP switch.—The GYRO LAMP switch (fig. 5–22) energizes the gyro motor, gyro lamp, and computer when placed in the ON position. This switch thereby activates the lead-computing properties of the sight unit. This function of the switch is true for each of the control boxes used with AFCS Mk 16.

The control boxes, which have two ON positions, are used with the Sight Unit Mk 11 which has a two-filament lamp. This arrangement provides a standby filament which can be utilized when one filament burns out. Control boxes with one ON position are used with the Mk 8 sight unit which has a single-filament gyro lamp.

FIXED LAMP switch.—The FIXED LAMP switch (fig. 5–22) is used to obtain the fixed reticle image on the reflector plate of the sight unit. The fixed image may be used as a reference in determining lead before uncaging, and may be used as an emergency sight if the gyro fails. The use of the fixed image is optional, and it can be turned off if not needed. The reason for some control boxes having two ON positions and others only one is the same as the arrangement discussed under the gyro lamp switch.

FIXED RANGE control.—The FIXED RANGE control (figs. 5–20, 5–22, and 5–23) is used in conjunction with the RANGE switch for radar (automatic) ranging or for fixed (pilot estimated) ranging. When radar ranging is used, the setting of the FIXED RANGE control determines the range at which an 800-cycle tone is produced in the pilot's headphones as his aircraft closes on the target. This tone is designated as the ranging tone and alerts the pilot that the target is within the preset firing range. The tone will be heard in the headphones as long as the aircraft remains within the range limits for firing. The tone will cease after the minimum firing range is reached, and the pilot must break away from the attack run to avoid collision with the target.

Although the starting point for the ranging tone is set by the pilot in positioning the FIXED RANGE control, the minimum range at which the ranging tone ceases is fixed in the internal circuitry of the range unit and cannot be altered by external controls. The actual setting for the FIXED RANGE control will be specified by squadron doctrine.

When fixed ranging (without radar) is being used, positioning the FIXED RANGE control sets an estimated value for the range into the computer. By visual means, the pilot determines when the aircraft has closed on the target within the preselected firing range. This application of the FIXED RANGE control is used for air-to-ground operations or when the radar set is inoperative during air-to-air attacks. No ranging tone is available in this mode of operation.

RANGE SWITCH.—The RANGE switch (fig. 5–22) selects the type of ranging to be used—RADAR or FIXED. The switch is placed in the RADAR position for radar ranging. The switch is placed in the FIXED position when the pilot is required to visually estimate his range, as in air-to-ground combat or during emergencies when the radar set is inoperative in the air-to-air mode.

GUNS-TEST-ROCKETS SWITCH.—The purpose of the GUNS-TEST-ROCKETS switch (fig. 5–22) is to adapt the fire control system to the type of armament to be used on a target, and to provide for flight testing the fire control system. When the switch is in the GUNS position, the system may be used for firing guns only; when the switch is in the ROCKETS position, the system may be used for rockets only. System mods may provide for the control of guns only, rockets only, or both. When installation is for guns only, the TEST and ROCKET positions of the switch are not used. When the installation is for rockets only, the GUNS position of the switch is not used.

The switch is placed in the TEST position when the alinement between the pipper and the flight path of the aircraft is to be checked. This cages the gyro and removes the gravity offset, but the pipper still responds to the attack and skid angles and the angle-of-attack adjustment on the angle-of-attack and skid compensator.

PANEL LIGHTS.—Each control box contains two panel lights which provide illumination for the various controls and switches. Power is supplied to these lamps through the aircraft console lighting circuit. In the event of lamp failure, replacement of the burned out lamp may be accomplished by removing the screw-on cap and inserting a new lamp in the receptacle.

ROCKET TEMP CONTROL.—The ROCKET TEMP control located on early mods of the Mk 35 control boxes is no longer used because recent developments have made this control obsolete. The control has been disconnected from the circuit of the fire control system, and has been omitted in the design of later control boxes.

VIS-ALT-AW SWITCH.—The VIS-ALT-AW (visual-alternate-all-weather) switch (fig. 5–20) is found on the Mk 43 control box. It has been added to adapt the system for all-weather use. In installations where this switch is NOT used, it may be set in any position. When used, this switch controls the mode of operation of the system. In the visual mode, aiming is accomplished by use of a pipper from a sight unit. The all-weather mode results in the proper point of aim being indicated on a radarscope. (See chaper 6, Armament Control System.) The alternate mode is provided in case of system failures.

PWR SWITCH.—The PWR switch (fig. 5–23) of the Mk 46 control box provides power to the system and energizes the gyro.

DIMMER-BRIGHT CONTROL. — The DIMMER-

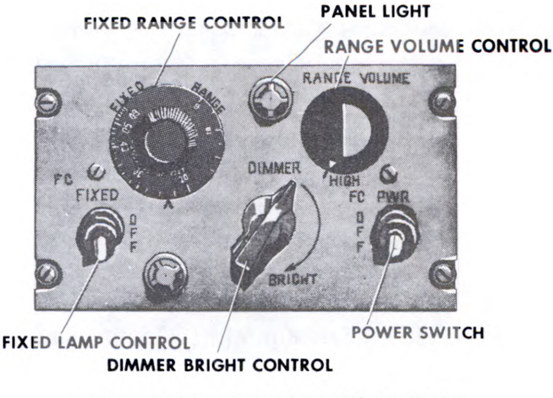


Figure 5–23.—Control Box Mk 46 Mod 0.

BRIGHT control (fig. 5–23) increases or decreases the intensity of the sight unit lamps.

RANGE VOLUME CONTROL.—The RANGE VOLUME control (fig. 5–23) is used to control the level of the audio signal. You will recall this system provides an 800-cycle audio signal to indicate when the aircraft is within a preset firing range.

Maintenance

As an Aviation Fire Control Technician 3, most of your maintenance work will be concerned with performing preflight checks and isolating troubles to major components. To perform these duties efficiently you must be familiar with the functional operation and operating control of the equipment given in the preceding sections. Also, you should develop some logical sequence for detecting and locating troubles. To help you organize a planned sequence for checking the PROPER performance of the equipment, and thereby detect trouble, the following PREFLIGHT CHECK is offered. Once again, you are advised to study (not simply read) these steps for they will help you to a better understanding of the equipment.

1. Make sure that all units of the system are securely installed. Determine that the chassis of the computers and the voltage regulator are secured to their cases. Check that all units are secured to the deck.
2. Check for frayed, worn, or otherwise damaged cables.
3. Inspect the surfaces of the reflector plate and collimating lens of the sight unit. If the surfaces are dusty, streaked, or smudged, follow the procedure given under the maintenance section for AFCS Mk 6 in this chapter.
4. The Sight Unit Mk 11 is provided with a desiccating unit (fig. 5–13) through which air enters or leaves the sight unit as the ambient pressure rises or falls during descent and ascent of the aircraft. During descent of the aircraft, air entering the sight unit is dehumidified as it passes through the desiccant. During ascent of the aircraft, the desiccant is reactivated by an automatically controlled electric heater

which causes the desiccant to free its moisture. The moisture is carried off by the outgoing air. Check to see that the color of the desiccant is a BRIGHT BLUE. Condensed moisture within the sight unit or continued pink coloring of the desiccant is an indication that the desiccant is saturated with moisture. In such a case, the sight unit must be removed from the aircraft and sent to an overhaul depot for repair.

If the system uses a Sight Unit Mk 8, follow the procedure given previously for the AFCS Mk 6.

5. Remove both the fixed and the gyro reticle lamps from the sight unit. If either lamp is darkened by use, replace it with a new lamp, using care to position it correctly in its socket.

NOTE: In order to continue this check it may be necessary to close the master armament switch to energize the system. Most activities require that the master armament switch be in the OFF position until the aircraft is off the ground (or ship). If the power to the fire control system is controlled by this switch, the technician must refer to the standard operating procedure of his command regarding the closing of the switch for conducting this check.

6. Turn on the fire control system by rotating the OFF-BRIGHT control clockwise, or throwing the POWER switch to ON. (On some types of aircraft it may be necessary to energize the inverter by closing another switch specifically provided for this purpose.)

7. With the GYRO LAMP and FIXED LAMP switches in their ON positions, check for a variation of the light intensity of the images by further rotating the OFF-BRIGHT control, or by rotating the DIM-BRIGHT control. The fixed and gyro images should be clear and steady. There should be no evidence of blur or fog on any part of the images. (Dust or grease on the exposed optical surfaces could cause the images to appear blurred.) Check both filaments of both lamps by switching to both ON positions.

8. With the gyro uncaged, and the RANGE switch in the FIXED position, place the GUNS-TEST-ROCKETS switch in the GUNS position. Rotate the FIXED RANGE control through its maximum displacement and observe the

pipper motion. Using the fixed image for a point of reference, the pipper should deflect in a downward direction from the zero axis of the fixed image when the FIXED RANGE control is rotated to the maximum range position. See figures 5–1 and 5–15 which show the fixed reticle pattern for the Sight Unit Mk 8 and Mk 11, respectively.

9. Place the GUNS-TEST-ROCKETS switch in the ROCKETS position, and again check the direction of the pipper motion when the FIXED RANGE control is rotated to the maximum and minimum ranges. The pipper should again deflect downward at the maximum range.

10. With the GUNS-TEST-ROCKETS switch in either the GUNS or ROCKETS position, the maximum downward pipper deflection should occur at the maximum range setting of the FIXED RANGE control, and the minimum pipper deflection should occur at the minimum range setting of the control. This deflection indicates that the fire control system is supplying a correction for gravity.

11. Place the GUNS-TEST-ROCKETS switch in the GUNS position and cage the gyro. The pipper should quickly move to a position which coincides with the center of the fixed image.

12. If possible, sight on a distant object at least 500 feet from the aircraft. In some situations it may be necessary to use an adaptor in place of sighting on a distant object. The reticle images should both appear superimposed on the object, without PARALLAX. As you will recall, to test for parallax you examine one image at a time, and move the head from side to side over the usable aperture of the lens. There should be no apparent shift of the image with respect to the target as the head is moved. If the image shifts more than three mils in any direction, the optical system is out of alinement, and the sight unit must be removed from the aircraft and sent to an overhaul depot for adjustment.

13. Operate the fixed reticle selector on the instrument panel out and in to see that it masks and unmasks the fixed reticle image.

14. At the completion of the preflight test, leave the gyro

caged and position the GUNS-TEST-ROCKETS switch for the armament to be used on the mission. For systems using the Sight Unit Mk 8 set the adjustable reflector to zero.

15. Any units that prove defective should be replaced at the aircraft. Any units still in question should be removed from the aircraft for bench testing.

TROUBLESHOOTING.—Let us now consider some aspects of troubleshooting a fire control system. This section is intended as an aid to you in developing a logical sequence in your troubleshooting procedure. The method of presentation will be (1) to state the observed SYMPTOMS, (2) one method of ANALYSIS to detect the faulty component, and (3) the REMEDIAL action taken. It is suggested that in studying this section, you stop after the symptoms and attempt your own analysis. It should be pointed out that there is usually more than one correct means of analyzing a defect in the equipment. Your method of analysis may not agree with ours, but it will be just as correct provided you use a logical sequence and come to the correct determination of where the trouble lies. Remember the most important point is to develop a logical sequence of analyzing the difficulty using the observed symptoms.

CASE 1. Symptoms: While making preflight check there was considerable movement of the fixed image with respect to the target, but no movement of the gyro image when the technician moved his head. Pretend for a moment that you are the technician. What is your analysis of the reported situation? Perhaps no trouble exists and the indications are normal. What would you do?

Analysis: The movement of either image with the movement of the head is an indication of parallax. Parallax is the result of a misalinement of the optical system.

Remedy: Alinement of the optical system is the responsibility of an overhaul activity. Therefore, the sight unit should be removed from the aircraft and sent to the overhaul activity.

CASE 2. Symptoms: While making a preflight check the technician noticed there was no fixed reticle image, but the gyro image was normal. Replacement of the fixed reticle lamp failed to cure the trouble. Wait! Have you made your analysis?

Analysis: Noting that the replacement of the lamp does not cure the trouble, leads to the conclusion that either the light rays are obstructed after leaving the lamp or that the lamp is not lit. Considering the first possibility would indicate an investigation of the light path from lamp to reflector. (See fig. 5–16.) This line of thought would suggest that the trouble exists in the reticle, the fixed reticle mirror, or the collimating lens. The mirror and the collimating lens can be eliminated for these parts are common to both fixed and gyro light paths and the gyro image does appear on the reflector. The possibility of an obstruction of the light path being caused by the setting of the masking control can be discounted because the masking control never completely masks the fixed reticle image. Thus, our first possibility centers around the sight unit. This possibility can be checked by the replacement of the sight unit.

The second possibility was that the lamp was not lit. In following this avenue of thought, the possibility of the lamp itself causing the trouble can be eliminated by the fact that replacement of the lamp did not cure the defect. Thus, we are led to the prospect of the difficulty being in the application of power to the lamp. (See fig. 5–21.) We know the power is reaching the control box because the gyro image appeared during the check. Thus, we have narrowed the suspect to three components: The control box, the sight unit, and the cabling between the two units.

In most installations the control box is easier to remove than the other components. Therefore, the logical place to look first would be the control box. If it is necessary to investigate the sight unit, it is suggested that a spare unit be connected to the cable before replacing the sight unit. The reason for this is that replacement of the sight unit requires boresighting the system. The prospects of the trouble being in the sight unit can thus be checked without removing the sight unit.

Remedy: In this instance, replacement of the control box remedied the trouble. The actual fault was in a defective FIXED LAMP switch.

CASE 3. Symptoms: The pilot reports that the ONLY difficulty when closing on the target, well within the firing range, was no firing tone. Replacement of the range unit did not cure the trouble.

Analysis: An examination of the block diagram in figure 5–21 shows that a range signal comes from the Computer Mk 86 to the range unit. Since the range unit generates the tone, the continued absence of tone after replacement of the range unit would indicate there are two major possibilities for this trouble: (1) in the system before the range signal enters the range unit, or (2) in the system from the range unit to the headset. Considering the first possibility, the trouble could be in the control box, Computer Mk 86, or in the interconnecting cables. Because lack of tone was the only symptom of the difficulty, it would be reasonable to suspect the cabling and not the components. The reason for this conclusion is that component difficulties would probably also affect the operation of the gyro and therefore the pipper. This would lead to an investigation of the cabling leading from the range unit to the pilot's headset. The headset and attached lead can be eliminated because there was no complaint of communication difficulties.

Remedy: Repair of the wire leading from the range unit to the pilot's headset remedied the trouble.

CASE 4. Symptoms: During a preflight check, the technician notes that the gyro image is blurred.

Analysis: Blurred images could be caused by dust or grease on the exposed optical surfaces. If this does not prove to be the source of trouble, then the difficulty exists internally in the sight unit.

Remedy: Since the repair of the sight unit is limited to overhaul activities, the sight was replaced and this action cured the defect.

CASE 5. Symptoms: While performing a preflight check, the technician notices that the gyro motor does not start when the GYRO LAMP switch is turned ON. Turning the

FIXED LAMP switch ON causes the fixed image to appear. Replacement of the sight unit and the switch box does not correct the trouble. Once again to get the most from this course, make your own analysis before continuing.

Analysis: Failure of the gyro motor to energize gives rise to two possibilities of difficulty: First, the gyro motor could be malfunctioning; and second, the power source and its control system could be the cause of the defect. The first possibility can be eliminated by noting that replacement of the sight unit did not correct the trouble.

In considering the second possibility, an examination of the block diagram in figure 5–21 reveals that power for the gyro comes from Power Supply Mk 75. The power supply, in turn, receives power from the inverter. We also know that the control box contains the switch that energizes the gyro. From these observations and the knowledge that replacement of the control box did not correct the difficulty, the trouble must be in one of three places: The Power Supply Mk 75, the inverter, or the connecting cables.

Remedy: Replacement of the Power Supply Mk 75 cured the trouble.

AIRCRAFT FIRE CONTROL SYSTEM MK 21

The AFCS Mk 21 series is basically the AFCS Mk 16 Mod 9 with the addition of the Converter Mk 32 Mod 0 and Gyro Unit Mk 38 Mod 0. If a radar is combined with the Mk 21 in such a way that the combination becomes an all-weather system, it is then called an ARMAMENT CONTROL SYSTEM (ACS). The purpose of this system is to present to the pilot an indication of the correct point of aim (total lead). As an ACS, this indication is available to the pilot by two means: The gyro reticle image of the sight, and a cathode-ray scope display. Although the Mk 21 is a portion of an ACS, discussion of Armament Control Systems will be reserved for the following chapter of this course. Because the AFCS and the ACS are so closely related, it is necessary at times to discuss portions of the ACS in order to complete the story on the Mk 21. Our consideration, now, is the Mk 21 itself.

Components and Functional Operation

An examination of figure 5–24 shows how the AFCS Mk 21 is tied in with the radar. Notice that without the two additional components, the system functions as AFCS Mk 16 Mod 9, and as such the target must be visible at all times during the attack. As an all-weather system, however, the scope presentation enables the pilot to make an attack even though the target is invisible.

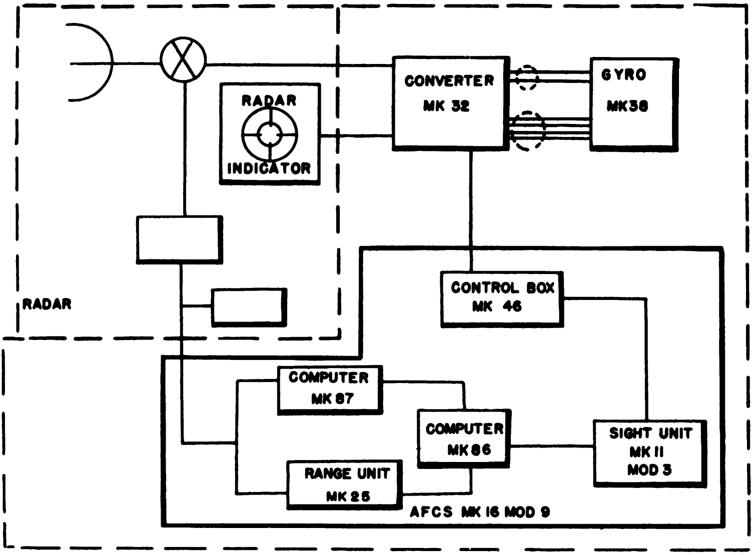


Figure 5–24.—Block diagram of the system.

Before presenting the two new components, it is necessary to point out that there are THREE MODES of operation of this overall system. These modes are:

1. VISUAL. In the visual mode, the radar and AFCS are used. Converter Mk 32 and Gyro Mk 38 are operating and a presentation will be on the scope. However, the pilot uses the pipper of the sight unit as an indication of the aiming

point. The sight unit lead pursuit display is corrected by temperature compensation. The scope presentation is only approximately correct being in error by an amount equal to the temperature compensation. In this mode the sight unit offers air-to-air optical lead pursuit gun and rocket firing.

2. ALL-WEATHER (AW). In the all-weather mode, the radar and AFCS Mk 21 are used. The cathode-ray scope indicates the proper point of aim to the pilot. The sight unit is in error because of no temperature compensation. The system offers lead pursuit gun and rocket firing for air-to-air operations.

3. ALTERNATE (ALT). The alternate mode is provided in case of system failures. In this mode, the sight unit offers air-to-air lead pursuit gun and rocket firing. The radar-scope presents air-to-air pure pursuit display. In the alternate mode, the system functions as in the visual mode. Should the radar fail, the pilot may use the sight unit for a visual indicator. However, the pilot must estimate range and range rate, since these are provided by the radar. If the Mk 21 system should fail, the radar would still indicate target position, range, and range rate. Lead would have to be estimated by the pilot. If the AFCS Mk 21 is defective, the pilot should not depend on the range tone. If this tone is present under these conditions, it is unreliable since this tone is supplied by a unit of AFCS Mk 21.

CONVERTER MK 32.—The Converter Mk 32 Mod 0 circuitry functions to select the three modes of different type displays for the attack phase. The converter (fig. 5–25) consists of six magnetic amplifiers, a system of relays, and two synchro channels. Its primary function is to receive input signals from the Computer Mk 86, reproduce, and, in some cases, amplify these signals. The converter receives the azimuth and elevation signal supplied by Computer Mk 86 to the sight unit and reproduces them for the Gyro Mk 38. It also receives the range output signal from the Computer Mk 86 and amplifies it for the range coils in Gyro Mk 38.

The synchro channels in the converter receive the actual lead-angle information from the radar and computer lead-

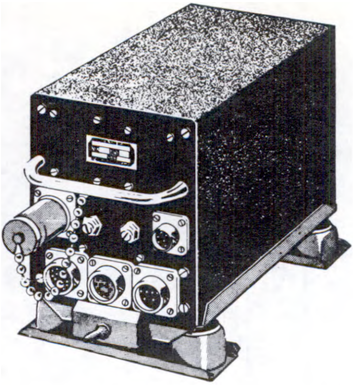


Figure 5–26.—Gyro Mk 38 Mod 0.

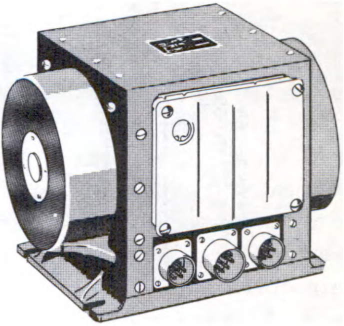


Figure 5–25.—Converter Mk 32.

angle information from the Gyro Mk 38. Circuits within the converter compare the two signals and then amplify the difference signal for presentation on the radarscope. When this difference signal is zero, the target pipper will be centered on the scope indicating to the pilot that he is tracking properly. The relays of the converter control the time sequence of operation of the system.

Gyro Mk 38.—The Gyro Mk 38 Mod 0 (fig. 5–26) is an eddy current constrained lead-computing instrument. The purpose of the gyro is to provide lead to the sighting indicator (radarscope). Based on the principles used in eddy current constrained gyros, the angles between the axis of the gyro and axis of the housing is the lead angle necessary to obtain hits.

Measurement of this lead angle is accomplished by a system of azimuth and elevation synchros in Gyro Mk 38. Electrical signals from the gyro unit containing this lead-angle measurement information are applied to the comparing circuits in Converter Mk 32. Here the signals are compared to the antenna positioning signal from the radar. After amplification the difference signal is used to control the target indicator on the scope. When the antenna signals null (equal and opposite) the gyro synchro signals, the target pipper will be centered on the scope face, indicating to the pilot that he is on target and tracking properly.

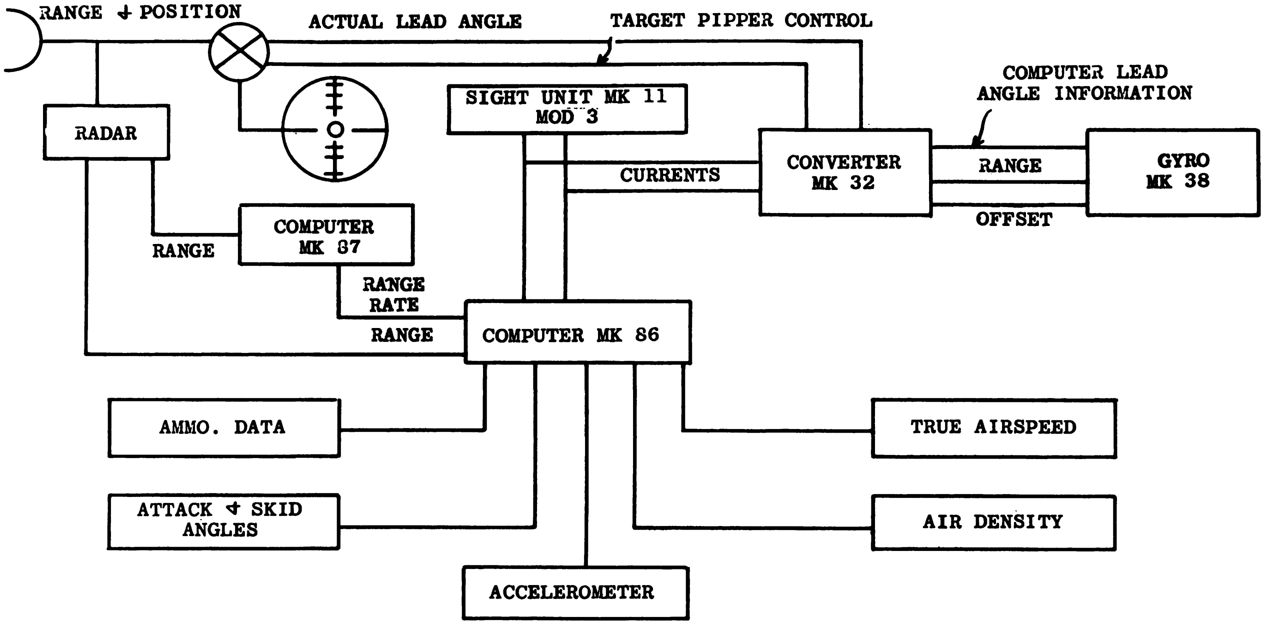


Figure 5–27.—Information flow for the system.

SUMMARY.—Let us now summarize the functional operation of the AFCS Mk 21 using the information flow diagram in figure 5–27. In this system, range which is measured in the radar is fed to Computers Mk 86 and Mk 87. The Mk 87 produces the range rate information. In the Computer Mk 86 the range, range rate, and ballistic factors are used to determine the range and offset currents. These currents are fed to both the sight unit and the Converter Mk 32. After amplification, the currents are applied to Gyro Mk 38 to aid in the determination of the lead angle. It should be noted that this lead angle contains the kinematic factors produced by the gyro and ballistic factors fed through the converter from Computer Mk 86 to the gyro unit. From the gyro unit the lead-angle information is then compared in the converter with the actual lead-angle information from the radar antenna. The resultant information is used to place the target indicator on the scope.

The all-weather system has two modes of operation in which it utilizes Converter Mk 32 and Gyro Mk 38. In the all-weather mode, electrical impulses from these units to the flight indicator provide the proper lead to acquire hits. Sight Unit Mk 11 is functioning at this time but without temperature compensation.

When the system is operated in the visual mode, temperature compensation is provided for the sight unit. Converter Mk 32 and Gyro Mk 38 function in this mode, but the scope presentation may be in error due to the dome temperature compensation for the sight unit being in the circuit.

When the system is in the alternate mode of operation, the components function as the AFCS Mk 16 with range and range only being supplied by the radar. In this mode of operation, there is a scope presentation representing target position. Should the Mk 21 system fail, the radar is available to the pilot.

Operating Controls

The operating controls, with two exceptions, for the AFCS Mk 21 appear on Control Box Mk 46 shown in figure 5–23. The purpose of these controls is the same as that given under the Mk 16 section of this course. For reasons of emphasis and completion of the description, the controls will be briefly reviewed.

The FIXED RANGE dial controls the electrical output from the fixed range potentiometer. The output voltage from this potentiometer is compared to the radar range voltage. When the two voltages become equal, an 800-cycle tone is heard in the pilot's headset, signaling when the target is within the preset range. When the pilot reaches his minimum allowable range, the tone ceases and break away is initiated.

The RANGE VOLUME control, as the name implies, controls the volume of the tone.

The PWR switch is the off-on switch for both the gyro and the gyro reticle lamp. This switch also controls the power input to the system.

The FIXED switch is the off-on control for the fixed reticle lamp.

The DIMMER-BRIGHT control is a variable autotransformer by which the intensity of the reticle lamps may be controlled.

The two controls which do not appear on the control box are the CAGE-UNCAGE switch and the FIXED RETICLE SELECTOR control. The former is a two-way switch and is usually on the throttle grip. In the cage position, the purpose of the switch is to constrain the gyro. Constraining, or caging, the gyro prevents tumbling during erratic flight. The FIXED RETICLE SELECTOR control is used to vary the fixed reticle pattern. This control is usually located on the aircraft control panel. Its exact location will vary with the type aircraft in which the system is installed.

NOTE: The previously mentioned controls are for the AFCS. For the all-weather system additional controls are necessary and usually appear on the radar control box. These additional controls will be discussed in a later chapter on Armament Control Systems.

Maintenance

Because the AFCS Mk 21 is so similar to the AFCS Mk 16, the maintenance section given for Mk 16 will apply to the Mk 21.

QUIZ

1. The two general classifications for describing fire control systems are
   a. director and disturbed systems
   b. director and velocity systems
   c. local and remote systems
   d. optical and radar systems
2. The AFCS Mk 6 series do NOT compute for
   a. angular turning rate
   b. range
   c. gravity
   d. altitude
3. The gyro dome in the Sight Unit Mk 8 tends to seek the
   a. electrical center
   b. frictional center
   c. mechanical center
   d. magnetic center
4. Caging of the gyro in the Sight Unit Mk 8 is accomplished by operation of the
   a. gunsight controller
   b. ranging throttle grip
   c. Range Unit Mk 17
   d. switch box
5. The amount of correction supplied by the air density compensator unit in the relay box of the AFCS Mk 6 is
   a. independent of air density
   b. inversely proportional to air density
   c. directly proportional to air density
   d. directly proportional to altitude

6. The voltage regulator used in the AFCS Mk 6 series is of the ________________ type.
   a. carbon pile
   b. finger
   c. electronic
   d. centrifugal governor
7. The target span lever in the AFCS Mk 6 is located on the
   a. relay box
   b. ranging throttle grip
   c. sight unit
   d. gunsight controller
8. Dry silica gel used in the Sight Unit Mk 8 should be
   a. amber
   b. pink
   c. white
   d. blue
9. When checking for parallax in AFCS Mk 6, the maximum permissible image shift is
   a. 3 mils
   b. 1 mil
   c. 2 mils
   d. 5 mils
10. In the AFCS Mk 6 Mod 3, as compared to previous mods of the AFCS Mk 6, the ________________ has been eliminated.
    a. sight unit
    b. gunsight controller
    c. relay box
    d. ranging throttle grip
11. In the AFCS Mk 6 Mod 3, the ranging throttle grip is used for
    a. both caging and stadiametric ranging
    b. stadiametric ranging only
    c. caging and uncaging only
    d. to preset range tone
12. Rocket offsets in the AFCS Mk 6 Mod 3 are set into the equipment by
    a. adjusting the sight unit
    b. a sight offset switch
    c. a rocket offset switch
    d. an adjustable reflector plate
13. Which component is referred to as the brains of the AFCS Mk 16?
    a. Computer Mk 86
    b. Range Unit Mk 25
    c. Sight Unit Mk 11
    d. Computer Mk 87

14. In the AFCS Mk 16, the attack angle and skid angle are compensated for in the
    a. gun firing only
    b. rocket firing only
    c. rocket and gun firing
    d. neither rocket nor gun firing

15. In the AFCS Mk 16, the output of the Power Supply Mk 75 is used to
    a. cage the gyro
    b. light the gyro and fixed lamps
    c. drive the gyro motor
    d. light the dial lamps

16. In the Sight Unit Mk 11, the masking control effects the pattern of
    a. the fixed image only
    b. the gyro image only
    c. both the fixed and gyro images
    d. neither the fixed nor gyro image

17. In the AFCS Mk 16, the setting of the fixed range control is utilized in
    a. determining when range tone ceases
    b. radar ranging only
    c. fixed ranging only
    d. fixed ranging and radar ranging

18. Alinement of the optical system of a Sight Unit Mk 11 is usually the responsibility of
    a. any instrument man
    b. the factory that manufactures the equipment
    c. a squadron maintenance man
    d. an overhaul activity

19. What determines when the range tone in the AFCS Mk 21 will commence?
    a. The setting of the FIXED RANGE dial
    b. Position of GUNS-TEST-ROCKETS switch
    c. Type radar used with the system
    d. Type of armament being fired

20. The fixed reticle selector control of the AFCS Mk 21 is usually located on the
    a. aircraft control panel
    b. control box
    c. throttle grip
    d. sight unit

21. The AFCS Mk 6 series are installed in
    a. patrol type aircraft
    b. fighter and attack type aircraft
    c. turrets
    d. fighter type aircraft and turrets

22. The AFCS Mk 6 Mod 0 is used for firing
    a. rockets and either .50 cal. or 20-mm guns
    b. rockets and bombs
    c. rockets only
    d. 20-mm guns only

23. In the AFCS Mk 6 series, the fixed reticle masking lever is located on the
    a. aircraft control panel
    b. throttle grip
    c. control box
    d. sight unit

24. The AFCS Mk 6 Mod 3 uses the ________________ sight unit.
    a. Mk 8 Mod 4
    b. Mk 11 Mod 1
    c. Mk 8 Mod 9
    d. Mk 11 Mod 2

25. In the AFCS Mk 16, the ouput of the voltage regulator is used to
    a. furnish range rate information
    b. drive the gyro motor
    c. supply range tone
    d. light the fixed and gyro lamps

CHAPTER 6

ARMAMENT CONTROL SYSTEMS

The statement "Certain airborne armament systems including control equipment and tracking and intercept components used in these systems" is included in a listing of aircraft armament equipment in the *Bureau of Aeronautics Manual*. Because you will be actively concerned with aircraft armament equipment, the entire meaning of this statement is important to you. As you will learn, these few words encompass a vast quantity of equipment and a multitude of concepts.

A consideration of the entire field of armament control systems will reveal several broad areas which, in turn, are subject to division into smaller sections. The purpose of this chapter is to mention the broad areas and then discuss types of equipment which are representative of the smaller subsections of one of these broad areas.

BASIC TYPES OF SYSTEMS

Aircraft armament control may be grouped into three main fields: Air-to-air, air-to-surface, and turrets or flexible weapons. As you would expect, a few types of equipment bridge this division and serve in two fields. Nevertheless, in this chapter our interest lies chiefly in the first of these fields—air-to-air. The other two fields will be considered in later chapters.

In the air-to-air field, types of armanent control systems also lend themselves to subdivision. The FIRST of these is the type of system in which the radar merely produces present information. The lead angle and future range calculation are performed within the aircraft fire control system. In this type system the target must be visible.

The SECOND type of armament control system includes means for calculating the required lead angle by means of a computer. In this system the radar provides range, range rate and angular information. This is a director-type system and is effective even if the target is not visible since a CRT is used to provide steering information to the pilot.

The THIRD subdivision is represented by a system in which data such as range, range rate, and other information necessary for solving the fire control problem are presented to the pilot on a cathode-ray oscilloscope, either as a lead angle or as an error signal. The optical sight in such a system is used when the target is visible.

These three basic types of air-to-air armament control systems may be described respectively as (1) visual disturbed-reticle-type system, (2) visual director-type system, and (3) all-weather system. The FOURTH and final system to be presented will be a missile guidance control system.

The typical armament control system, then, is a complete system for computing lead angles and may consist of both radar and optical equipment. In the past some of its components were furnished by the Bureau of Aeronautics and some by the Bureau of Ordnance. The equipment using the AERO system of nomenclature was BuAer furnished, while the Mark and Mod system denoted BuOrd equipment. However, recent organization changes have given BuAer complete responsibility for all components of Aviation Fire Control Systems.

VISUAL-DISTURBED RETICLE

The radar set in this type of armanent control system is usually a lightweight, automatic range only (ARO) radar which supplies target information to a lead-computing optical gunsight system for use in day fighter aircraft. The ARO concept is not by any means new, since records indicate that early types were under test in World War II. Since this time, the ARO radars have been continuously improved and, as in the Korean conflict, have proved themselves valuable to the fighter pilot.

Both the Mk 6 and Mk 16 types of AFCS are used with ARO radar. Recall that the Mk 6 Mod 3 and Mk 16 AFCS, as given in the preceding chapter, required a radar for ranging. Because the Aircraft Fire Control Systems have been discussed, the discussion in this section will center around the radar and the system of connecting the radar and the AFCS to obtain the armament control system (ACS).

Block Diagrams

ARO RADAR AND AFCS MK 6.—The block diagram in figure 6–1 shows an ARO radar used in conjunction with AFCS Mk 6 Mod 0, 1, or 2. This system has two modes of operation: Radar ranging and manual or throttle grip ranging. In this system the transmitter generates two pulses. One pulse is eventually emitted by the antenna as radio energy. The other is sent to the range converter where it provides a zero time reference for the range circuits. When the transmitted pulse strikes a target, energy is reflected back to the antenna. This energy is conducted to the receiver where the pulse is detected, amplified, and fed to the range computer.

The range computer generates a d-c range voltage proportional to the time interval between the transmitted pulse and the received pulse. The time interval is proportional to the distance between the aircraft and the target.

This range voltage is then fed to the servo amplifier. Another voltage, controlled by the gunsight controller and representing the angular position of the flexible shaft, is also supplied to the servo amplifier. The amplifier then supplies a drive voltage to the relay control of the controller motor which turns the flexible shaft until the two input voltages to the amplifier are equal. In addition to supplying a voltage proportional to the range of the target, the range computer also produces a signal which essentially locks-on the target. Thus, the range information is fed to the sight

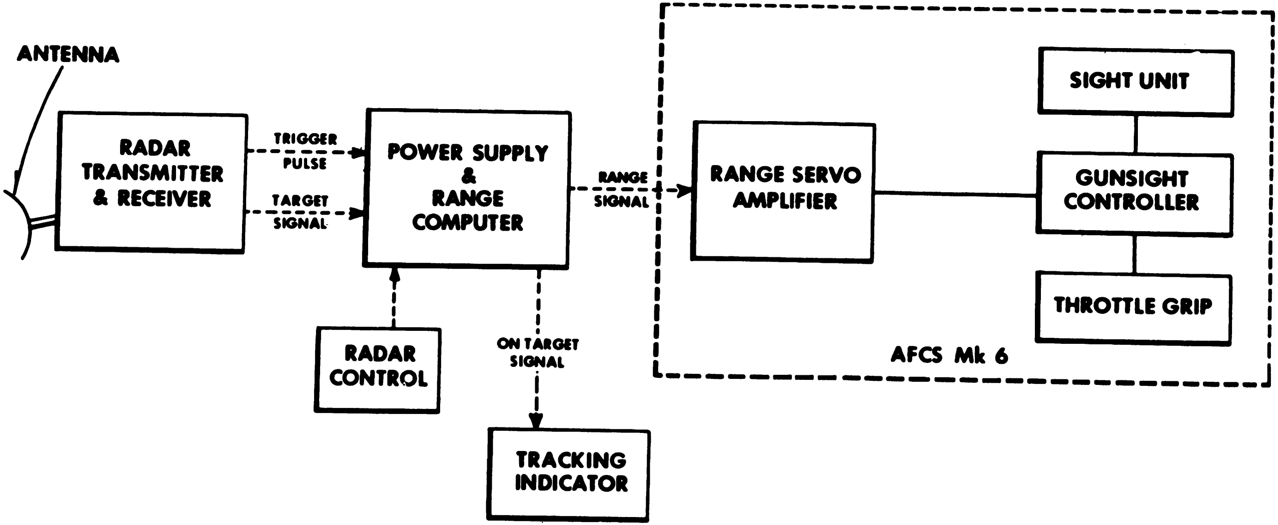


Figure 6–1.—Block diagram of ARO radar and AFCS Mk 6 Mod 0, 1, or 2.

unit where it is combined with the other necessary information. The sight unit produces the correct lead for obtaining hits on the target by displacing the gyro reticle image on the reflector plate. The throttle grip, in this system, is used only for locking and unlocking the gyro.

In manual operation of this system, the ranging is provided by the ranging throttle grip. Recall from the Mk 6 AFCS discussion that the diameter of the pips is controlled by rotation of this grip. The ranging throttle grip is connected to the gunsight controller which in turn is connected to the range unit on the sight unit. Thus, the ranging throttle grip in conjunction with the wingspan lever stadiametrically determines the range to the target.

ARO RADAR AND AFCS MK 6 MOD 3.—The block diagram in figure 6–2 shows an ARO radar used in conjunction with AFCS Mk 6 Mod 3. This system differs from the Mod 0, 1, or 2 in that (1) the range unit of the sight unit is replaced with a hand-operated manual range assembly, (2) a range data converter is used, and (3) the gunsight controller is eliminated.

The information flow in the system shown in figure 6–2 is very similar to the previously discussed system. Once again the radar generates the pulses which energize the radar transmitter and provide a zero time reference for the range circuits in the range computer. As before, the transmitter antenna emits radio energy which strikes a target and is reflected as an echo. The receiver picks up this echo and after amplification passes it to the range computer.

The range computer generates a d-c range voltage proportional to the time interval between the transmitted pulse and the received pulse. The time interval is proportional to the distance between the aircraft and the target. This range voltage is fed to the range data converter which converts it into a nonlinear direct current. This current is modified for temperature and altitude variations and then supplied directly to the range and elevation coils of the gyro. With the proper range current supplied to the gyro, the sight unit will provide the proper lead for firing the guns in air-to-air operation.

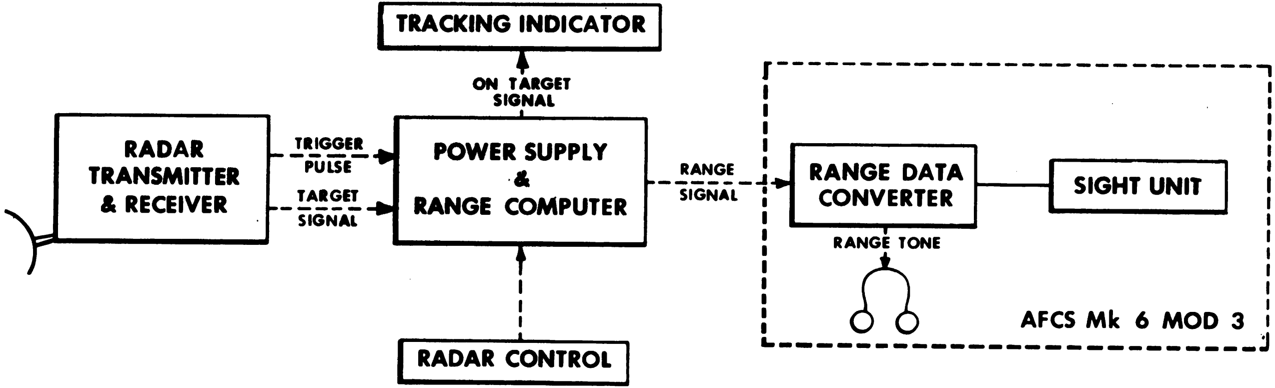


Figure 6-2.—Block diagram of ARO radar and AFCS Mk 6 Mod 3.

The range data converter also contains a tone generator circuit. When the radar locks-on a target, this circuit generates a 400-cycle tone which is heard through the pilot's headphones. As the pilot tracks the target, the range voltage decreases. At some preset range, a relay is energized which causes the tone generator to change the tone to one of 800 cycles. This 800-cycle tone continues throughout the firing range. When the pull-off range is reached, the tone generator circuit switches back to the 400-cycle tone.

Note that one of the major differences in this system is that the range voltage directly controls the currents to the gyro. Thus, the use of this equipment does not require the estimating of the target dimension by means of the target span lever. However, means are provided for setting a fixed range current value into the sight unit by the MANUAL RANGING KNOB. This knob, as the name implies, is used for manual operation of the system. The ranging throttle grip in this system is used only for caging and uncaging the gyro.

ARO RADAR AND AFCS MK 16.—The block diagram in figure 6–3 shows an ARO radar used with a Mk 16 type of AFCS. As in the previous systems, the radar produces the range to the target. However, in this system, the target range information is fed to two computers. One of these determines the range rate and then feeds this information to the other computer. In the Computer Mk 86 the range, range rate, and ballistic information is combined and the output is the proper gyro control current to obtain the desired lead.

Note that the major difference in the ACS utilizing the AFCS Mk 16 is the method of determining the proper currents to control the gyro and thereby the gyro image. In this system, the throttle grip is merely a switch for caging or uncaging the gyro. Other differences between the Mk 6 and the Mk 16 systems have been discussed in a previous chapter.

Function of the Radar

The function of the radar in this system is to provide automatic range only (ARO). The radar transmitter is triggered at a predetermined rate and simultaneously gener-

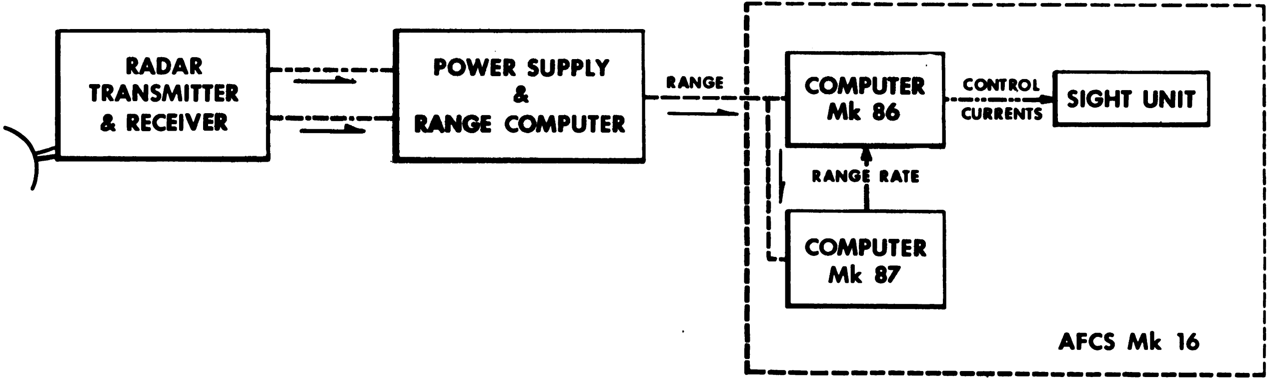


Figure 6–3.—Block diagram of ARO radar and AFCS Mk 16.

ates two pulses of very short duration. One of these is converted into a pulse of RF energy emitted by the antenna. The other pulse is used as a trigger pulse to provide a zero time reference for the range circuits. The RF pulse travels through space away from the antenna at a constant known velocity until it strikes an object. When this happens, some of the energy is reflected back toward the radiating antenna. This energy is received by the antenna and conducted to the receiver where the pulse is detected and amplified to a useful level. The envelope of radiofrequency pulse received, commonly known as "video," is fed to the range computer.

The range computer determines the time difference between the transmitted pulse and the received pulse, and generates a d–c voltage proportional to this time difference. Since the propagation velocity of electrical energy in space is a constant, this time interval is proportional to the distance between the radar equipment and reflecting object. Thus, the range voltage output of the range circuits may be calibrated directly in distance units to the object or target. It should be noted that this range voltage is fed to another device before the range information is used to control the gyro.

A tracking indicator is used to warn the operator that the equipment is tracking in range. The tracking indicator (fig. 6–4) consists of a small indicator mount containing a socket and indicating lamp. This indicator is usually mounted on or near the gunsight in full view of the pilot. Usually, means are installed to control the brightness of the light to afford proper indication under various conditions of natural and artificial light.

Also, the range computer usually contains a circuit which, in the absence of a target, causes the radar system to search specific ranges which are manually selected. It also has a circuit to stop the search function whenever a target is detected, and a circuit which causes the system to respond to signals from only one target at a time. Miscellaneous circuits for generating automatic gain control voltage for the receiver and for regulating the noise level of the receiver are also used. In addition, there are circuits which supply range

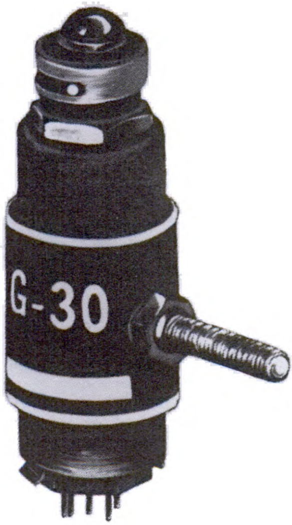


Figure 6–4.—A tracking indicator.

information to a height indicator. The characteristics of this type of radar may be summarized as follows:

1. Automatically search in range.
2. Automatically "lock-on" and thereafter track a target in range.
3. Automatically warn the operator when the equipment is tracking a target.
4. Automatically provide target range to a system for operation of a lead-computing sight system.
5. Utilize a sight system and do not provide target indications on a radarscope.

The Aircraft Fire Control System

The function of the AFCS in this type of armament control system is to supply all the needed information, with exception of the range, and then solve the fire control problem. Although the method of solution has been discussed in a previous chapter, it is appropriate to briefly review this method of solution using radar ranging.

We have seen that there are two basic types of AFCS—the Mk 6 and the Mk 16. The means of indicating the proper lead to the pilot is essentially the same in both systems. The center pip of the lead-computing reticle image establishes a sight line which is automatically offset from a fixed or reference sight line. The offset of this pip of light corresponds to the proper lead angle for obtaining hits. By use of this image and radar ranging, the pilot's problem is simplified to positioning the aircraft so that the dot of the movable image remains on the target until the attack has been completed.

The actual solution of the fire control problem takes place in the AFCS. In the Mk 6 system, range and ballistic information enters the problem by control over the currents that determine the magnetic field for the spinning gyro disks. Movement of the aircraft in tracking the target is detected by the gyro. Thus, the ballistic and kinematic factors, including range from the radar, are equated in the lead-computing gyro system.

The Mk 16 utilizes a computer to determine the correct currents that are fed to the gyro field coils. In this computer the range, range rate, and ballistic information is equated to determine the correct gyro field currents. Once again the movement of the aircraft is detected by the gyro. Another feature of the Mk 16 is the use of gravity compensation.

Purpose and Use of Controls

A typical ARO radar control box is shown in figure 6–5. This particular control box contains three controls. The first, the POWER, has three positions: OFF, STANDBY MANUAL, and ON RADAR. The STANDBY MANUAL position permits the radar to warm up and permits manual ranging with the fire control system. When automatic radar tracking is desired, the switch is placed in ON RADAR. A guard is placed over the master control switch to prevent accidental operation of this in place of the OUT switch.

The second control, the RANGE MAX knob, adjusts the

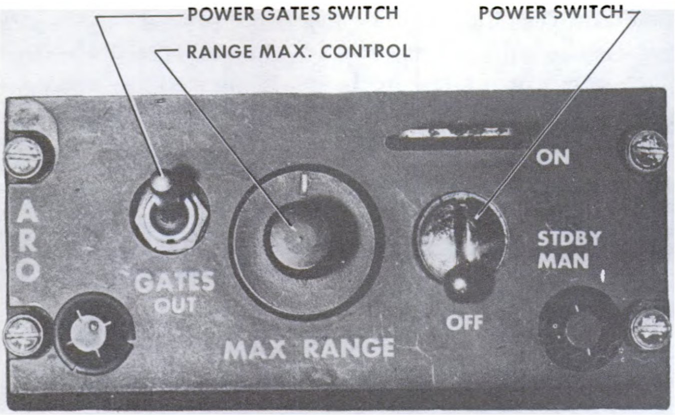


Figure 6–5.—Typical ARO radar control box.

maximum radar range for search. (See fig. 6–5.) At low altitudes, the control is used to reduce the range so that the radar does not lock-on ground targets. The third control, the RANGE GATES switch, is a spring-loaded switch. When it is depressed to OUT, the radar unlocks from a target and locks-on the next target in range. If no other target is within maximum range, the radar sweeps and again selects the initial target.

These three controls are the only controls necessary for the operation of this type of radar. For the operation of the armament control system, it is also necessary to properly set the controls of the AFCS. Because the fire control system controls have been thoroughly explained in the previous chapter, they wil not be discussed further.

Maintenance

As an AQ3, the majority of your maintenance activities on this type of ACS will be concerned with the fire control portion. Usually, you will NOT be occupied with circuit analysis within the radar, radar computer, or power supply. Nevertheless, you are responsible for energizing and securing the equipment, setting the operating controls, and making operational tests. Besides being able to locate and identify major components and subassemblies, you should be capable of isolating casualties to major components.

A careful and thorough preflight check will usually disclose any malfunctions in the equipment. If any discrepancies exist, a logical analysis of the entire system, coupled with a knowledge of the part each block plays in the system, will enable you to isolate the casualty to a major component. Therefore, to do your part you should have a good knowledge of the information flow from block to block and the function of each block in the system. Further, you should carefully and thoroughly perform the prescribed operational tests to disclose any difficulty in the system.

To aid you, the following preflight check is suggested for this type of ACS. It will serve as a general outline for such a check or test. The majority of operating units will have a detailed procedure for you to follow.

1. Make sure that all units are securely installed. Check the retaining screws of all vibration mounts. Tighten loose screws and replace sheared or defective retaining screws.
2. Examine all external cabling or frayed insulation, particularly where cables enter connector plugs or cable clamps, or where they pass through bulkheads. Repair or replace any defective cables. Make sure that all connector plugs are drawn up securely on their receptacles.
3. Inspect the antenna for secure mounting. Tighten all interconnecting cables. The waveguide should be intact and undistorted.
4. Check all fuses.
5. Place the power switch on STANDBY MANUAL. Allow a three to five minute warmup period.
6. While the equipment is in standby condition, perform the preflight check for the AFCS.
7. Turn the POWER switch to ON RADAR. If an indicator is used to show the operating condition of the radar, check this indicator for proper performance.
8. Note if the radar locks-on a target. The ranging or tracking indicator should show when the radar has locked-on a nearby target.

9. Press the RANGE GATES switch. The radar should jump off the target to another target if available.

10. If the Mk 6 system is in use, check to see that the diameter of the circle of pips varies with targets at different distances. In the Mk 16 system, check for a change in lead when the distances between targets change.

11. Return the radar to STANDBY MANUAL and fire control system to OFF. Turn the radar switch to OFF position.

VISUAL-DIRECTOR SYSTEM

This type of armament control system is, as its name implies, a system that uses both optics and electronics (radar) in the solution of the fire control problem. In this type of system the sighting information is presented to the pilot both by means of a radarscope and visually by a movable reticle image.

Block Diagram

The block diagram for this type of ACS (fig. 6–6) shows the relation between the various units of the system. The block diagram also shows the flow of information between the units. In the radar, means are provided for detecting and tracking the aerial target. By measurement of the time interval between when the radio energy leaves the antenna and when the echo returns, the distance to the target is determined. This information is fed to the computers in AFCS. Here the ballistic and flight information is used with this range information to determine the range and offset currents. These currents flow to the sight unit where they aid in determining the visual indication of the proper lead angle. The currents also are fed through a converter to a gyro where they supply the range and offset information.

The gyro, which is a lead-computing instrument, determines the lead angle from the input information and the gyros response to the turning rate of the aircraft. This computer lead angle signal then is fed to the converter where it is compared with the actual lead angle information derived from the antenna's position. The output from the converter

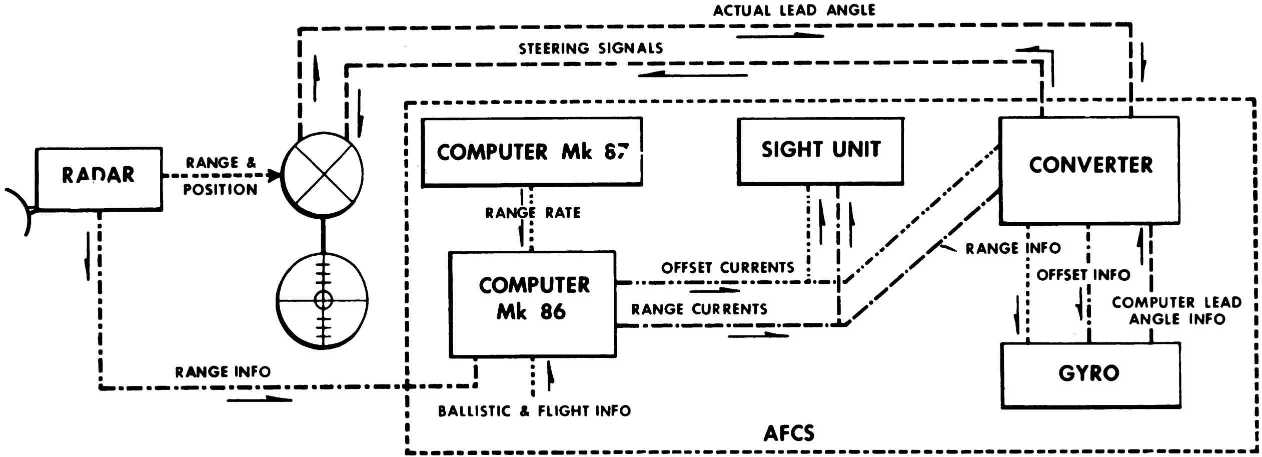


Figure 6–6.—Block diagram of optical and radar ACS.

is used to indicate on the radarscope the steering information necessary for the pilot to obtain the correct lead angle.

Radar Modes of Operation

This type of armament control radar system has three modes of operation for the search and attack phases of a mission. These modes and their characteristic scope displays may be given the descriptive names of (1) automatic search, (2) manual search, and (3) automatic track. Incidentally, the modes usually follow this order in appearance during a mission.

Automatic search.—During automatic search, the antenna scans an area ahead of the aircraft with certain sections of this area being selected for scanning by the settings of the controls. As shown in figure 6–7, the scan pattern is a two-line Palmer type scan generated by rotating the beam while the antenna centerline follows a two-line wigwag pattern. That is, the antenna centerline sweeps in azimuth, drops vertically a few degrees, sweeps in azimuth in the opposite di-

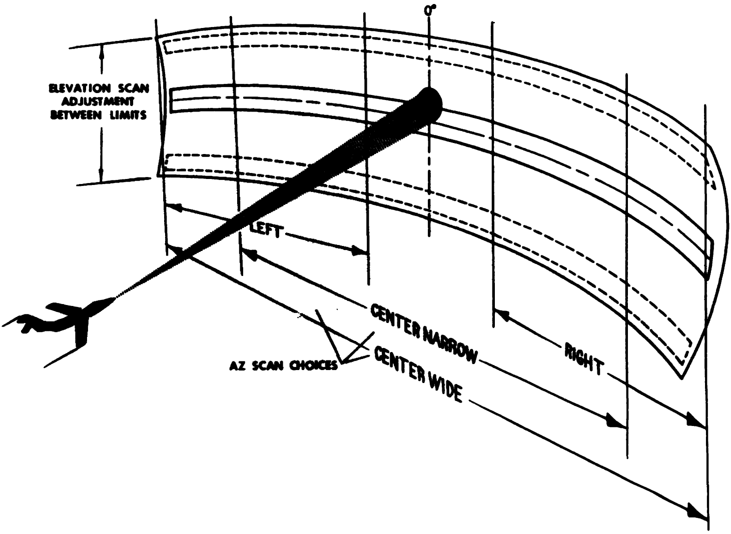


Figure 6–7.—Automatic search scan pattern.

rection, and then rises vertically to the start position. This action is repeated continuously. The elevation of this scan is adjustable between certain limits by the use of EL SCAN and the HAND CONTROL. A marker on the right side of the screen shows the elevation of the antenna during each scan. There are four azimuth scans available. As shown in figure 6–7, they are LEFT POSITION, CENTER NARROW, CENTER WIDE, and RIGHT POSITION. The desired azimuth scan is selected by the AZ SCAN control.

The search display (fig. 6–8) is a conventional type B scan displaying range and azimuth. Targets are shown as bright spots on the scope. Notice in the figure that range is indicated vertically from the bottom, and azimuth readings are read from scales engraved on the top or bottom of the scope.

The search display also includes an artificial horizon, which represents the position of the actual horizon with re-

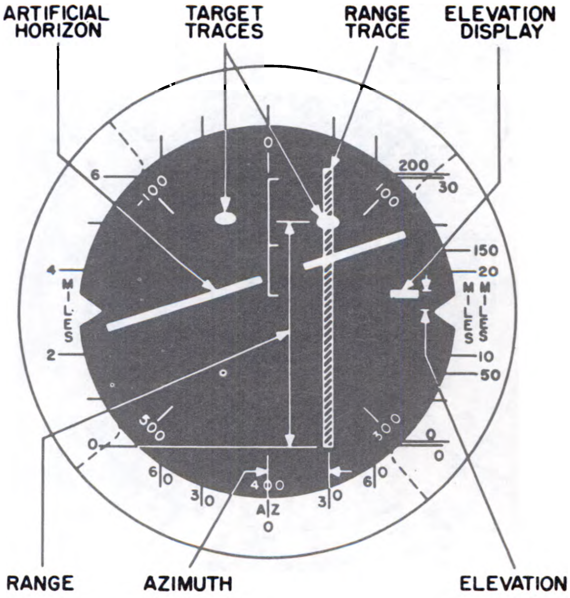


Figure 6–8.—Automatic search scope display.

spect to the plane. Diving or climbing is indicated by the vertical position of the artificial horizon, above or below the center, respectively. Roll angles are indicated by the apparent tilt of the artificial horizon on the indicator scope. Notice in figure 6–8 that there is a gap in the center of this line to keep the center of the display clear.

Manual search.—After a target has been located during automatic search, manual search is employed to establish radar lock-on to the target and start the automatic track mode. To place the system in manual search, an action switch on the antenna control lever is held down. The scope display presented in this function is the manual search display. (See fig. 6–9.) It is essentially the same display as automatic search except that a range gate marker is provided. The range gate marker consists of sharp leftward displacement of the range sweep trace as shown in figure 6–9. The vertical position of the marker corresponds to the range

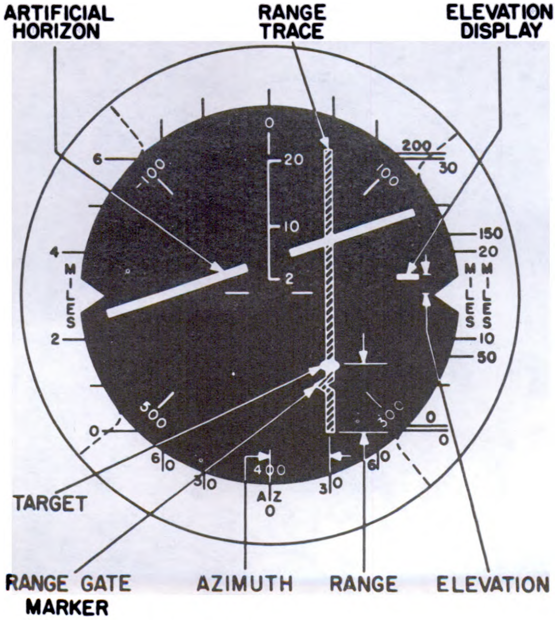


Figure 6–9.—Manual search scope display.

at which the system range tracking circuit will lock-on and track a target.

By moving the antenna control lever the pilot positions the antenna until the radiated beam is focused on the target. He then utilizes the range gate marker. By employing a range IN-OUT switch on the antenna control, the range marker is moved down or up. This marker is moved until its position coincides with that of the target indication. At this point lock-on occurs, the pilot releases the action switch, and the system enters automatic track.

Automatic track.—When the equipment is locked-on a target, the attack display automatically appears. (See fig. 6–10.) This display presents to the pilot the steering information to complete the attack. The pilot flies the scope by maneuvering so as to first center the steering circle on the scope and then center the steering dot within the steering circle. When the steering dot is centered, the target is dead ahead and the aircraft is flying toward the target on a pursuit

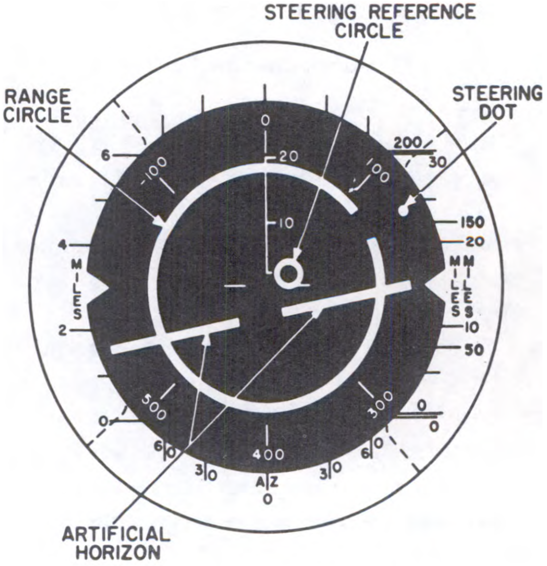


Figure 6–10.—Automatic track scope display.

course. Because of its greater sensitivity, the steering dot provides greater accuracy.

In this mode of radar operation, the antenna is locked-on the target. Once again the artificial horizon appears as in the search display and serves the same purpose. Range information is provided by a range circle. The radius of the circle represents the range of the target, the circle becoming smaller as range decreases. The range is read from a scale etched on the front of the scope. The opening or closing rates are read from an etched circular scale on the face of the scope. This rate is indicated by the break in the range circle with zero rate being at the top center of the scope. Closing rates are located to the right of top center, and opening rates are indicated on the left of the display.

It should be noted that when the target becomes directly visible, the pilot can complete the attack by use of the optical sight. Under adverse visibility conditions, the complete firing run can be made by observing the radarscope. There are other considerations in the pilot's determination of which type of final sighting to use, but these are essentially tactical and do not fall within the scope of this course.

Radar Components and Functions

The functions of this type of airborne intercept radars are (1) air search, (2) automatic (lock-follow) tracking of airborne targets, (3) surface search, and (4) radar beacon navigation. The primary function of the radar is the detection of airborne targets and lock-follow tracking of a selected target. Beacon and long range surface search functions are provided as navigational aids.

The block diagram of a typical fire control radar is shown in figure 6–11. In this system there are eight functional sections: Synchronizing, transmitting, RF transmission, receiving, indicating, range-tracking, antenna-positioning, and service. By use of this block diagram, let us briefly investigate the purpose and use of each functional section and also follow the information flow.

SYNCHRONIZING SECTION.—The synchronizing section gen-

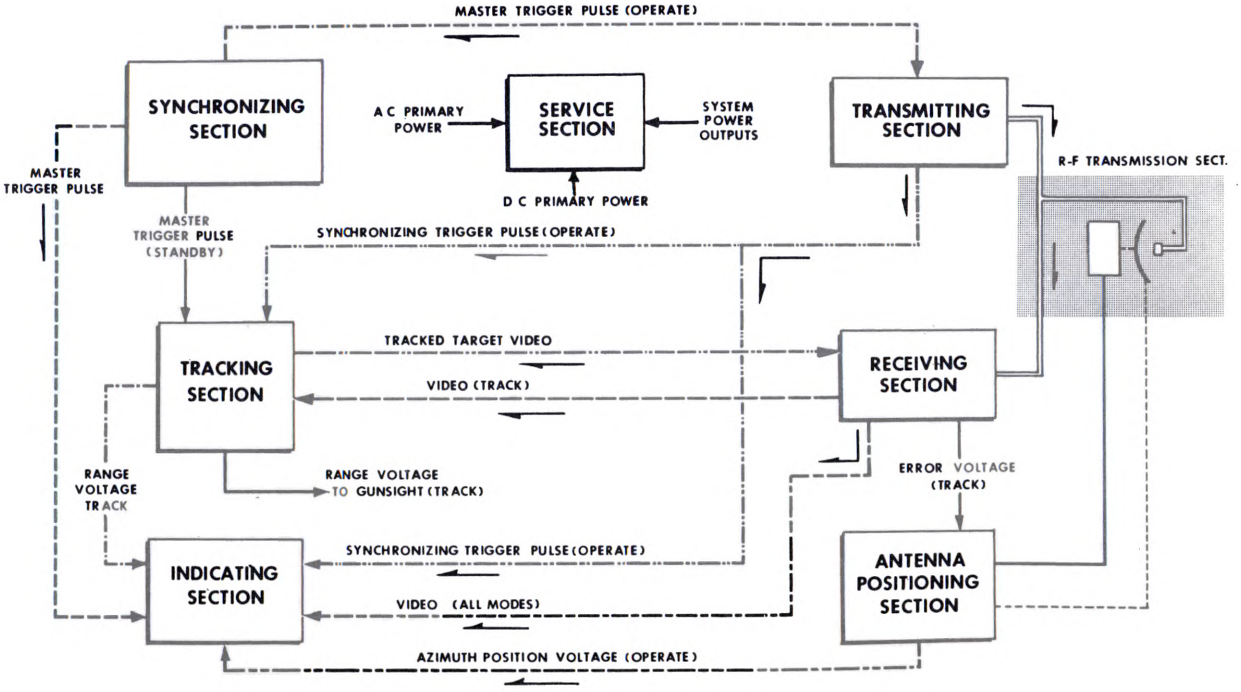


Figure 6–11.—Functional block diagram of a typical fire control radar.

erates the trigger pulses for timing the operation of the entire system. When in operate condition, the master trigger pulse is delivered to the transmitting section where it establishes the pulse repetition frequency (i. e., how many times a second the radar transmits energy). In standby condition, the master trigger is fed to the range tracking section. The master trigger pulse is also delivered to the indicating section in both operate and standby condition. In the indicating section, the trigger pulse is used to start the range sweep, presented on the flight indicator (scope). In the range-tracking section, the trigger is used to start a precision sweep for the range measuring circuits.

Transmitting section.—The transmitting section generates high power RF pulses at a rate which is timed by the master trigger pulses from the synchronizing section. The transmitting section also provides a synchronizing (called sync) pulse in time with the transmitted RF pulse. This sync pulse is fed to the range-tracking and indicating sections.

RF transmission section.—The RF transmission section couples the RF energy developed in the transmitting section to the antenna. A switching arrangement allows one antenna to be used for both transmitting and receiving. Thus, the antenna is alternately transmitting and receiving RF energy. The received energy is coupled through the RF transmission section to the receiving section. An azimuth and elevation voltage is also produced and fed to the antenna positioning section.

Receiving section.—The receiving section receives target echo and beacon signals from the RF transmission section. These signals are amplified and detected to supply video signals to the indicator, range-tracking, and antenna-positioning sections. In automatic track operation, an error signal for antenna positioning is developed from the signal returned from the range-tracking section. This error signal is applied to the antenna-positioning section and is used to indicate when the tracked target is not located in the center of the beam of the antenna.

Indicating section.—The indicating section generates the search and attack displays presented on the screen of the flight indicator. The cathode-ray tube is of twin-gun construction, the electron beams of both the search and attack guns creating the display being superimposed on the single screen. The attack gun presents the attack display and search gun presents the B scan and video for the search display. In search display, the range trace on the scope is developed in the indicating section. This trace is started by the master trigger pulse while its azimuth position is determined by information from the range-tracking and antenna-positioning sections. Thus, the synchronization between the position of the antenna in azimuth and that of the range trace on the cathode-ray tube is obtained. The indicating section also contains the means for converting the received information into the attack display.

RANGE-TRACKING SECTION.—The range-tracking section accepts the master trigger and tracked-video echo signals as input information and furnishes a signal proportional to range as output. The range information is conveyed to the indicating section and the AFCS where it is used in the solution of the fire control problem. This section also generates the signal which is forwarded to the indicating section to provide the range gate marker.

In addition, the range-tracking section provides the signal that converts the radar to automatic track mode of operation. You will recall, in this mode the attack display appears. Thus, the lock-on operation is completed when the pilot releases the action switch.

ANTENNA-POSITIONING SECTION.—The antenna-positioning section contains drive motors for positioning the antenna in azimuth and elevation. In automatic search, the antenna follows a selected pattern determined by the AZ SCAN switch. This control is exercised through a controller which programs the antenna pattern. Elevation of the pattern is determined by the EL SCAN control.

In manual search the antenna-positioning section converts the information received from the pilot's antenna control lever into the signal which positions the antenna. In automatic track mode the error signal circuitry of the antenna-positioning section controls the angular positioning of the antenna.

Service section.—The service section distributes the power required for the radar set. Normally included in this section would be power supplies, a voltage regulator, terminal boxes, and a radar test set.

Space stabilization.—Another feature of this type of radar for use in armament control systems is space stabilization. Stabilization of the radar's search scan pattern is provided to prevent the pattern from being affected by the roll and pitch of the aircraft. Without stabilization, the scan pattern is affected by maneuvers of the interceptor, and airborne targets are easily lost. With stabilization, the scanning of the antenna is independent of the fighter's roll and pitch, and the antenna scans the same relative area ahead of aircraft regardless of aircraft attitude. Figure 6–12 shows the effect of space stabilization in the search mode of operation.

The primary advantage of stabilization stems from the fact that, in order to provide the most effective search cov-

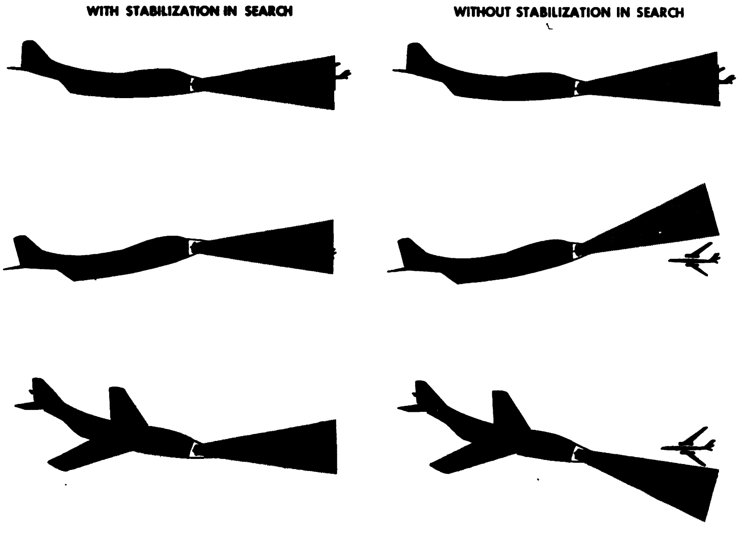


Figure 6–12.—Effects of space stabilization in tracking a target.

erage, the antenna has been designed to scan a much larger sector in azimuth than elevation. Without stabilization, roll of the aircraft would cause the scan pattern to miss completely a target located near the edge of the pattern.

Stabilization is also helpful during surface search operation in providing a steady pattern of surface targets on the radarscope regardless of aircraft maneuver. Some radars have special gyros for this roll and pitch control, while others use the aircraft's autopilot gyro.

Aircraft Fire Control System

The function of the Aircraft Fire Control System in this type of ACS is to provide ballistic and kinematic information for the solution of the fire control problem. The flow of information between the radar and the AFCS is shown in figure 6–6. In this figure the AFCS Mk 21 is used, but other AFCS are used with this type of radar.

The AFCS is an electromagnetic and electromechanical computing device used to aid the pilot in aiming the guns and rockets. The system by use of radar ranging, magnetic computers, and a gyro computing sight presents the point of aim to the pilot. In the AFCS, this point of aim is indicated by a gyro reticle image and is accurately computed for service types of guns and rockets.

For the operation of this type of ACS, the majority of the information is supplied by the radar and Computer Mk 86. As shown in figure 6–6, the radar furnishes a voltage proportional to range to Computers Mk 86 and Mk 87. In the Computer Mk 87 the range voltage is converted to range rate voltage. The range and range rate information, together with the ballistic information, are evolved into a solution of the fire control problem by Computer Mk 86. This solution is sent to the respective coils of the gyros in the sight unit where they control the position of the pilot's visual indicator, the gyro pipper. This information from Computer Mk 86 is also used via the converter and gyro units for the determination of the steering signals. These steering signals are used to control the position of the target on the scope.

A study of the Mk 21 AFCS in the preceding chapter reveals that there are three modes of operation of the ACS; namely all-weather (A-W), visual (VIS), and alternate (ALT) modes. In the visual mode, the radar and AFCS are both used, but the pilot uses the sight unit as an indication of the aiming point. The alternate mode is provided in case of system failures. The all-weather mode uses both the radar and AFCS, with the radarscope providing the proper point of aim. In the all-weather system, the radar has three modes or phases of operation; namely, automatic search, manual search, and automatic track.

Purpose and Use of Controls

To round out our discussion concerning the radar, let us now consider the controls, their purpose, and use. The following description is intended to aid you in setting the operating controls and in energizing and securing the fire control radar. We will first consider the control panel for our typical system. (See fig. 6–13.)

MASTER SWITCH.—This is a four-place rotary switch (fig. 6–13) used to control the input power to the radar system. The OFF position, normally used by maintenance personnel, completely deenergizes the system. The STB position will hold the system in readiness for immediate operation, after furnishing warmup power to the system components, during the normal 3 to 4 minute time delay period. The OP position completely energizes the equipment. STB position may be bypassed initially and the switch set on OP in order to automatically energize the entire system following the normal time delay. In either position the equipment is given a warmup period before full operation. Incidently, a warmup waiting period is found in all fire control radars. The time delay can be eliminated under extreme emergency conditions by turning the MASTER switch to the EM position to immediately energize the entire system. NOTE: Extensive use of the EM (emergency) position will shorten the life of vital system components.

OPER SWITCH.—The OPER switch (fig. 6–13) is a five-

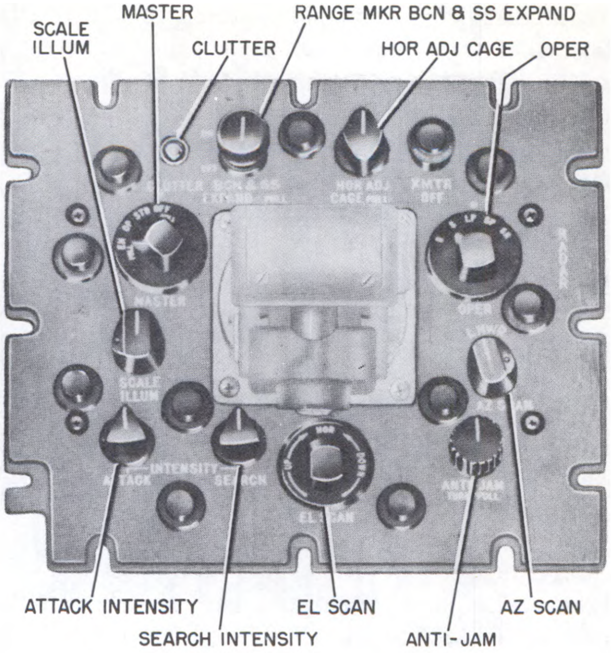


Figure 6–13.—Fire control radar control panel.

place rotary switch which controls the mode of system operation. In addition, the range sweeps are selected by the switching action. The LP, long pulse, position is normally used for automatic air search operation. The SP, short pulse, position is used to resolve echoes from nearby objects and to prevent undesired triggering of beacon stations while performing normal air search operation. The SR, short range, position is similar to SP operation. However, it is limited to a much shorter maximum range in order to obtain still higher resolution of short range target echoes when flying in a tight formation. With this switch in the S position, the equipment provides surface search. While in the B, beacon, position, the system operates with the required beacon triggering characteristics.

SCALE ILLUM CONTROL.—The SCALE ILLUM control (fig. 6–13) varies the brightness of the scale illumination lights on the face of the flight indicator.

Panel illumination controls.—Each of the unlabeled controls on the control panel varies the intensity of the illuminating light for the switch to which it is adjacent.

SEARCH INTENSITY control.—This control (fig. 6–13) varies the brilliance of the search display on the flight indicator screen. The control is set correctly when there is maximum contrast between targets and background.

ATTACK INTENSITY control.—This control (fig. 6–13) varies the intensity of the attack display on the indicator screen. Normal setting is just below the point of image fuzziness on the screen.

EL SCAN control.—The EL SCAN control (fig. 6–13) provides continuous elevation positioning of the antenna within prescribed limits about an initial position as determined by the antenna hand control. If the antenna hand control is in the normal position, the HOR position of the EL SCAN control will place the center of the scan pattern at zero degree elevation with respect to the horizon. However, the antenna hand control can vary the elevation position the same amount as the EL SCAN control. Thus, coordinated use of the EL SCAN and the antenna hand control gives a maximum elevation coverage of the antenna.

AZ SCAN control.—The AZ SCAN control (fig. 6–13) is a four-position switch used to select the azimuth scanning limits of the antenna during automatic search, beacon, and surface search operation. The area of forward scan as determined by the L (left), N (narrow), W (wide), and R (right) positions of the control is shown in figure 6–7.

ANTIJAM control.—This switch (fig. 6–13) is to be used to avoid jamming (enemy interference) or other interference. For further information on this control, you are referred to the service manual for the equipment containing such a control.

HOR ADJ CAGE control.—This is a dual-purpose control. It is used for vertical centering of the artificial horizon. Also, by pulling the control, fast erection of the vertical gyro can be obtained. Both adjustments must be made with the aircraft in level flight position. Caging the gyro is normally necessary by the pilot after violent maneuvers.

RANGE MKR EXPAND CONTROL.—Beacon and surface search operation employ a range marker strobe, used for expansion in range of a selected portion of the display. A certain portion immediately above this range marker on the sweep may be expanded to cover the entire indicator screen. Turning the control moves the marker along the sweep to the desired range sector, and pulling the control displays the expanded sector.

CLUTTER ELIMINATOR SWITCH.—The CLUTTER eliminator switch (fig. 6–13) is a two-position toggle switch. With the switch thrown to the ON position, the clutter eliminator prevents the display of echoes due to ground or sea return. The switch is normally set in the OFF position.

REDUCED POWER LAMP. — Lighting of the REDUCED POWER lamp (fig. 6–13) indicates that a transmitter overload has occurred and that the system has gone into a condition of reduced power output to remove the overload. In normal operation this lamp is not lit. Depressing the lamp housing will light the lamp to indicate that it is working properly.

ANTENNA HAND CONTROL.—The function of the antenna hand control (fig. 6–14) is to vary the position of the antenna in azimuth and elevation during MANUAL search operation. During AUTOMATIC search, it is used to control the antenna's elevation as described under the EL SCAN section. Rolling the control to right or left directs the antenna right or left. Forward and backward motion of the hand control produces corresponding downward and upward movement of the antenna.

ACTION SWITCH.—The ACTION switch, seated in the forward portion of the control grip, is a spring-loaded bar type control which must be pressed to place the system in MANUAL search. Closing the action switch couples the antenna electromechanically to the hand control.

RANGE IN-OUT SWITCH.—The RANGE IN-OUT switch (fig. 6–14) is a four-position rocker type control which the pilot operates by thumb pressure. It is used in MANUAL search operation to move a range gate marker inward and outward in range along the range sweep trace until the position of the marker coincides with that of the target. The range gate marker can be made to move either slowly or rapidly, depending upon whether the switch is partially depressed or fully depressed.

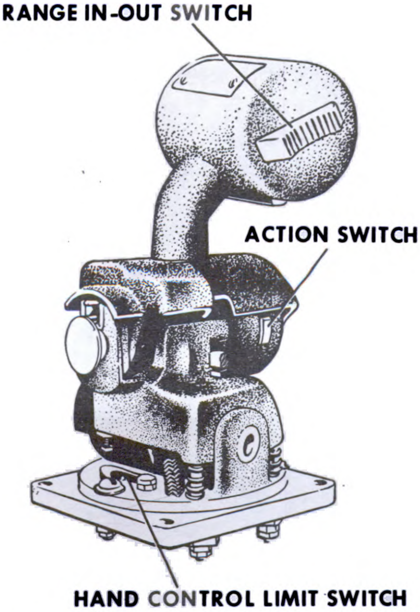


Figure 6–14.—Antenna hand control for fire control radar.

Hand control limit switch.—The hand control limit switch is located on the rear base of the hand control lever and is not normally visible. It is used to return the system from manual search or automatic track operation back to automatic search. The switch is actuated when the hand control is moved as far backward as possible. The action switch must be open during this operation. When the limit switch is actuated, the antenna returns momentarily to the dead ahead position and then begins to scan normally.

A second typical control panel.—Let us now consider another control panel (fig. 6–15) used with a fire control radar of different design. Essentially, the two radars are used for

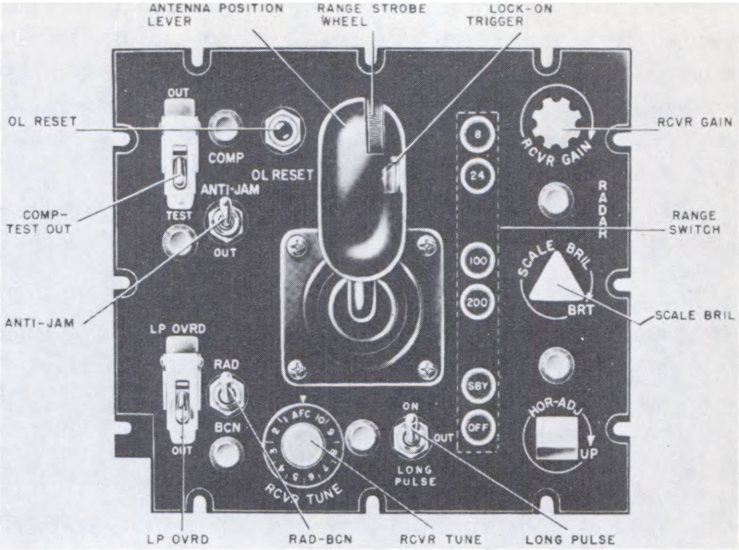


Figure 6–15.—Operating controls for a fire control radar set.

the same functions. In considering this second control panel, our purpose is twofold; namely, description of controls not used in the previous control panel, and discussion of other methods of exercising control.

On this control panel (fig. 6–15) the RANGE switches determine the maximum operating range of the equipment and in conjunction with other controls determine the type of operation. Note that these are pushbutton type of controls with the SBY button used for standby position. In place of selecting the SBY button, one of the range switches can be selected to turn on the equipment. If one of these switches is pressed first, the equipment will go into full operation after a warmup delay.

Many of the controls of the two radars have similar purposes. The RAD-BCN switch selects radar or beacon operation. The HOR ADJ performs the same function as the previous HOR ADJ control—vertical positions of the artificial horizon line. The function of SCALE BRIL is the same as the SCALE ILLUM control, and the ANTIJAM switch has the same use as well as name.

Several controls appear on this second panel that were not used on the first. The RCVR GAIN control adjusts the intensity of targets on the scope during search operation by controlling the gain (amount of amplification) of the radar receiver. During track operation the RCVR GAIN usually loses all control and gain is adjusted automatically. RCVR TUNE permits manual tuning of the receiver. Although performed differently, this tuning is the same as the fine tuning control on a television set.

The IFF switch (fig. 6–15) has three positions. (Recall from chapter 2 that IFF means identification, friend or foe.) ON position is for continuous IFF interrogation; in OUT position the equipment is not interrogating; and in MOM position, IFF interrogation lasts as long as the switch is held down. LP OVRD-OUT permits system operation when pressurization of components is lost. In the OUT position, normal pressure protection is in effect. OL RESET button is pressed to restore full operation after transmitter overload.

COMP-OUT-TEST switch is used in conjunction with the computer; COMP position being used for normal operation. The OUT position is used when the computer is operating improperly. When the switch is in this position and tracking a target, the target's indication on the scope represents its present position since lead angle is not supplied. The TEST position, as its name indicates, is used for a test of the computer's operation.

The ANTENNA POSITION LEVER performs the same action as the ANTENNA HAND control during search operation. It is also used for steering of the antenna during lock-on. In the equipment using the control panel shown in figure 6–15, lock-on is obtained by the use of three controls. To lock-on a target the RANGE STROBE WHEEL on the antenna positioning lever is rotated until the range strobe lines bracket the target. (See fig. 6–16.) The selected target then appears on the gun aim portion of the scope; the gun aim portion is a C-type display. To select a target on the gun aim scope for automatic tracking the circular

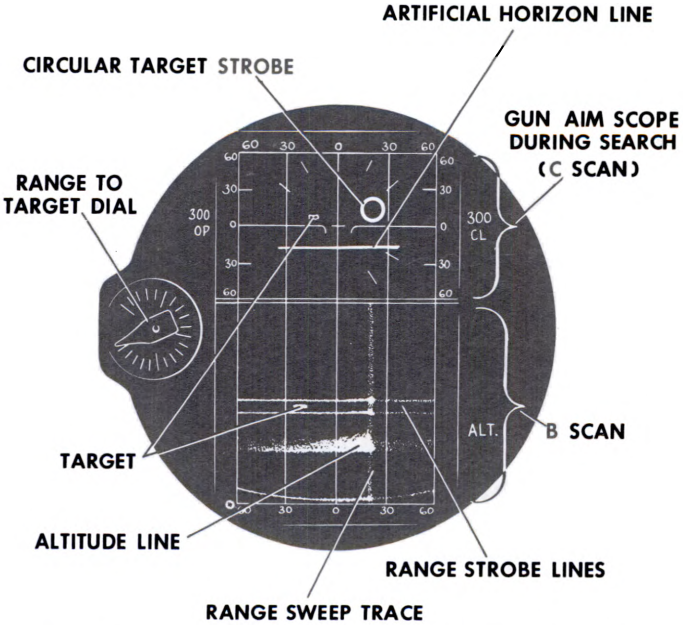


Figure 6–16.—Gun aim and B scan display of fire control radar.

target strobe is positioned by the ANTENNA POSITION LEVER until it encircles the target.

When the target is contained within this strobe and the LOCK-ON TRIGGER is depressed, the antenna locks-on the target and the system switches to automatic track. In automatic track, the presentation on the gun aim portion of the scope differs greatly from the search display and the antenna automatically tracks the target. After tracking has begun, movement of the antenna lever has no effect on the antenna position. Lock-on may be discontinued by pressing the LOCK-ON TRIGGER a second time.

Maintenance

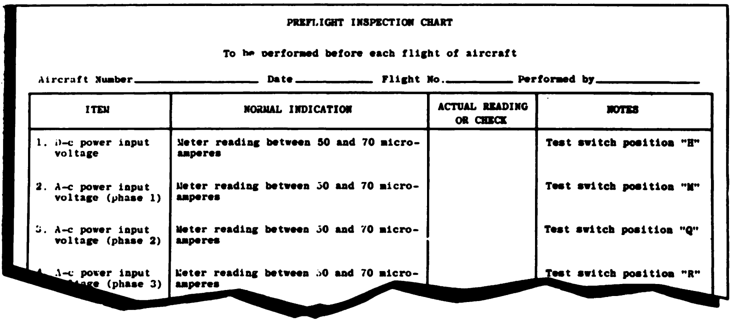
A consideration of the maintenance problems involved in this type of armament control system results in the separation of the maintenance into two parts—the AFCS and the fire control radar. The first part was discussed in chapter 5 of this course, leaving our attention to the maintenance of the radar.

Probably the one single factor that will be the greatest aid to you in your maintenance of the radar is the *Handbooks of Service Instructions* (HSI). These books have two chapters specifically devoted to maintenance problems. Chapter V is concerned with organizational and operational maintenance while chapter VI pertains to field and FASRon maintenance. The organizational maintenance is usually at the squadron level and consists of those maintenance procedures that may be performed while the equipment is still installed in the aircraft. The FASRon level of maintenance includes maintenance procedures which deal with the individual components of the radar.

These chapters of the service manuals usually include a description of the various inspections required. Very often the preventive maintenance schedule is outlined in the form of charts. Included in the required inspections are: Preflight inspection, daily inspection, intermediate inspection, special inspections, and major inspections. The preflight inspection is performed before each flight. No major test equipment is required, and usually no access doors or equipment cases need be removed.

The daily inspection is performed before the first flight each day. Performance of the intermediate, special, and major inspections is scheduled for predetermined intervals of aircraft operating hours. This inspection schedule represents the minimum preventive maintenance required, and may be modified by a particular operating organization. In addition to the regular inspections, the technician should always watch for troubles, such as broken leads and loose connections which can be detected visually. A portion of a typical inspection chart is shown in figure 6–17.

Systematic performance of the periodic inspection procedures will usually reveal any troubles that may develop in the system. Attention should be given to all indications of troubles no matter how slight. This attention is recommended so that troubles caused by slow deterioration can be located and corrected as early as possible. You will find some



PREFLIGHT INSPECTION CHART

To be performed before each flight of aircraft

Aircraft Number________________ Date__________ Flight No._________ Performed by______________

ITEM	NORMAL INDICATION	ACTUAL READING OR CHECK	NOTES
1. D-c power input voltage	Meter reading between 50 and 70 microamperes		Test switch position "H"
2. A-c power input voltage (phase 1)	Meter reading between 50 and 70 microamperes		Test switch position "M"
3. A-c power input voltage (phase 2)	Meter reading between 50 and 70 microamperes		Test switch position "Q"
A-c power input tage (phase 3)	Meter reading between 50 and 70 microamperes		Test switch position "R"

Figure 6–17.—A portion of a typical inspection chart.

equipments require quality checks; that is, determination of HOW WELL the equipment is operating.

Some of the troubles that occur may be located immediately by analysis of the symptoms. Many more, however, are not easily located, since a particular symptom may be the result of any one of a number of possible defects. Systematic procedures must then be used to locate and correct the trouble. In some cases, the trouble may be located by observation of arcing, the presence of smoke, discoloration of parts due to heat, or cold tubes.

Many troubles may be the result of misalinement or drift of critically adjusted circuits, and realinement of the suspected circuit may be the only remedy required. Care should be taken, however, that any adjustments attempted do not result in MISALINEMENT of a circuit in which no misalinement is present. Complete alinement procedures are usually given in the *Handbook of Service Instructions.* When a procedure is performed independently, due consideration should be given to other circuits that might be affected by the adjustment.

As examples of some of the external adjustments you may be called upon to make, consider those shown on the flight indicator in figure 6–18. This flight indicator is the one containing the scope displays in figures 6–8, 6–9, and 6–10. To properly make these adjustments, it is first necessary to set the system controls in the normal positions as given by the service manual.

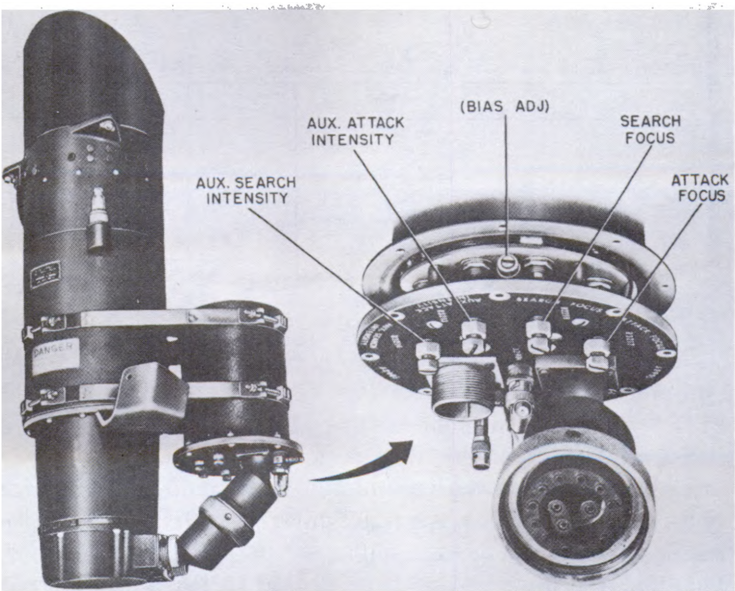


Figure 6–18.—External adjustments on a flight indicator.

Assuming that these SYSTEM controls have been set, we are now prepared to adjust the controls in figure 6–18. First, turn the ATTACK INTENSITY control (fig. 6–13) on the radar set control fully counterclockwise. Now, adjust AUX ATTACK INTENSITY control on the flight indicator until the attack display barely disappears with the indicator screen well shaded. You should then advance the ATTACK INTENSITY control for a display of proper intensity, and adjust the ATTACK FOCUS control of the flight indicator for a sharply defined display. It must be possible to make the attack display plainly visible in bright daylight by adjustment of the ATTACK INTENSITY control.

A similar procedure is used in making the search display adjustments. Once again the system controls are set to the normal position and the SEARCH INTENSITY control on the control box is turned fully counterclockwise. The AUX SEARCH INTENSITY control is then adjusted until the range trace barely disappears with the screen well shaded.

You now advance the SEARCH INTENSITY control for a display of proper intensity, and adjust the SEARCH FOCUS control on the flight indicator for a sharply defined range trace. It must be possible to make the search display plainly visible in bright daylight by adjustment of the SEARCH INTENSITY control. When the controls are properly adjusted, the potentiometer's locking nuts should be tightened.

From the discussion just presented, it should be noted that to properly complete these adjustments you must consult the appropriate service manual. This discussion was intended to show, in a general way, the intensity and focus adjustments. These controls on a radarscope essentially perform the same function as the intensity and focus controls found on a television set.

NOTE: Extreme care should be exercised if and when the cover is removed from an indicator for it contains voltages which are dangerous to life.

ALL-WEATHER SYSTEM

The all-weather armament control system is used in fighter-intercepter aircraft. The detection of the target and solution of the fire control problem takes place within the radar and associated electronic equipment. The computer of an AFCS is not used in the solution of the problem as it was in the just-discussed ACS. This, of course, does not preclude the possibility of this type ACS being used with an AFCS and the target information being displayed by both optical and radarscope means.

Block Diagram

The information flow between major blocks of this type ACS is shown in figure 6–19. Here the radar generates the synchronizing pulse which triggers the transmitter resulting in the radiation of energy. This RF energy travels through space until it encounters an object and then is reflected back to the radar antenna. The reflected energy is detected and

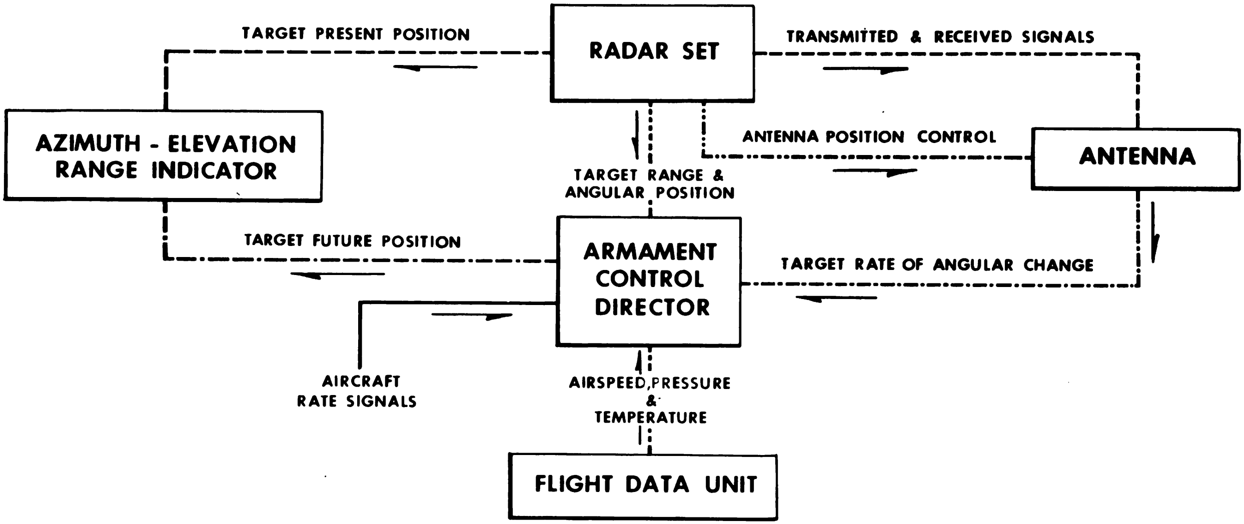

TARGET PRESENT POSITION
RADAR SET
TRANSMITTED & RECEIVED SIGNALS
AZIMUTH - ELEVATION RANGE INDICATOR
ANTENNA POSITION CONTROL
ANTENNA
TARGET RANGE & ANGULAR POSITION
TARGET FUTURE POSITION
ARMAMENT CONTROL DIRECTOR
TARGET RATE OF ANGULAR CHANGE
AIRCRAFT RATE SIGNALS
AIRSPEED, PRESSURE & TEMPERATURE
FLIGHT DATA UNIT

Figure 6–19.—Block diagram of nonoptical radar ACS.

amplified, and the time interval between transmission and reception used for determining range.

The radar's information—range and angular position—is used to supply present target position to the indicator. Further, the radar supplies target range and angular position to the armament control director.

In the director, this information is used with the airspeed, air pressure, and air temperature from the flight data unit plus the angular rate of change from the antenna and the aircraft rate signal to determine target future position. Thus, the armament control director uses the kinematic and ballistic information to compute the required lead. The indication of the correct point of aim is shown on the indicator screen from the supplied information—the target's present and future positions.

If an AFCS were to be used with this type of system, it would be possible to feed the range and range rate information from the radar to a computer. Such a computer as the Mk 86 would then add the ballistic information and compute the correct current for control of the field of a gyro. The gyro action would add the kinematic factors and thus produce the solution of the fire control problem or the correct point of aim.

Function and Components of the Radar

In a typical installation, the radar set operates as a member of the armament control system in conjunction with the armament control director and the flight data unit. The system is capable of locking-on a target and tracking it, thereby automatically supplying information to the pilot which will enable him to carry out an effective attack on the target.

In addition to its function of supplying tracking information to the system, the radar set is capable of air intercept search (AI) and air-to-surface vessel search (ASV). It also has provisions for interrogating beacon and IFF equipment, and displaying their responses.

The major units of such radar sets are the synchronizer, the receiver-transmitter, the power supply, and the antenna sections, but for ease of discussion we will divide the radar into four systems utilizing the various sections. The four systems are: The transmitting system, the receiving system, the indicating system, and the automatic tracking system.

TRANSMITTING SYSTEM.—The transmitting system consists of a pulse repetition frequency (PRF) generating circuit, a modulator, RF plumbing, a waveguide, and a reflector-type directional antenna. A trigger pulse is developed in the synchronizer section and used to trigger the modulator. The modulator develops a high positive potential which is discharged by the trigger from the synchronizer. This high potential is applied to a special tube called a magnetron, shocking it into oscillation, and causing RF energy to be generated for the duration of the applied pulse. The RF energy is then passed through the waveguide to the antenna where it is radiated in a unidirectional pencil-shaped beam. A switching arrangement, called a duplexer section, connects the antenna to the magnetron during transmitting time and to the receiver during the time interval between transmitted pulses.

RECEIVING SYSTEM.—The reflected radar echoes are received by the antenna and passed through the waveguide, where they are mixed with the output from the radar local oscillator resulting in a lower frequency called the intermediate frequency (IF). This IF is fed to the amplifiers in the receiver-transmitter section and then to the synchronizer section. In the synchronizer the signals are further amplified and detected and then fed to the B and C scopes of the indicator and to the tracking circuits for automatic tracking.

A portion of the transmitted signal is used for the operation of the automatic frequency control (AFC). The AFC output controls the frequency of the radar local oscillator, maintaining the IF output at a constant frequency.

The receiving system operates in the same manner in beacon operation as in radar operation, except that the beacon signal is not of the same frequency as the radar signal. However, the output from another oscillator, called the beacon local oscillator. is maintained at a corresponding difference frequency. Thus the intermediate frequency, which is the difference between beacon and beacon local oscillator frequencies, is as before. It is possible, therefore, to use the same IF amplifiers in both beacon and radar operation.

INDICATING SYSTEM.—The indicating system consists of those circuits concerned with the display on the indicator. A three-gun cathode-ray tube is used in the indicator to present target information to the pilot. The upper portion of the tube, known as the gun aim scope, presents a target dot display during gun aim operation which represents the point in space at which the gun should be fired to score a hit, as determined by the control director. The lower portion, a B scope, displays azimuth and range during both gun aim and search operation. The signal outputs from the synchronizer section are applied to both the B and C scopes.

During search and track operation, the gun aim scope presents the target selector line, a vertical trace, and an artificial horizon line. This C scope also gives target elevation and azimuth information during search operation. To select a target for automatic tracking, the target is straddled on the B scope by the range strobe lines and the target selector line is moved until it is alined in azimuth with the target. The range strobe lines are two parallel lines positionable on the scope screen by means of the range strobe wheel. The position of the target selection line is controlled by the antenna positioning lever. Now, when the lock-on button is depressed, automatic tracking is initiated.

AUTOMATIC TRACKING SYSTEM.—During automatic tracking, the B scope presents range and azimuth information of the target selected for tracking. The antenna scan pattern on the gun aim scope is replaced by a range rate circle and target dot after lock-on. (See fig. 6–20.) The dot represents the computed aiming error as determined by the director. The artificial horizon line remains unchanged. An intensified dot on the range circle shows the rate of change of range of the targe by angular displacement on the circle, while the diameter of the circle is in direct proportion to the target range. Closing speed is denoted by clockwise

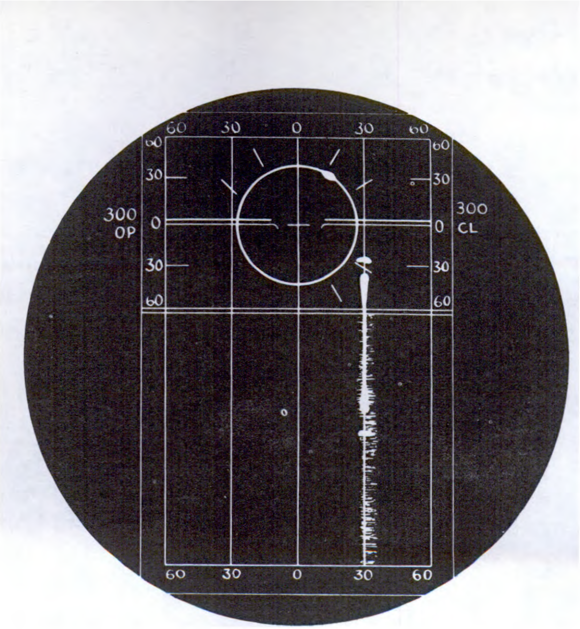


Figure 6–20.—Scope presentation during automatic track.

displacement and opening speed by counterclockwise displacement from the reference line.

Automatic range tracking is performed by circuits in the synchronizer section. These circuits compare the elapsed time between the radar trigger and the target signal with the elapsed time between the radar trigger and a generated range signal. This generated range signal occurs at the same time as the range strobe when there is no target motion. Any target movement is detected and a resulting error signal causes the range strobe to move in the direction of target movement until the error signal is nulled. Thus, the strobe stays locked-on the target. Also during automatic tracking, a system of error voltages drives the antenna in both azimuth and elevation so that the axis of the scan remains on the target.

Armament Control Director

The armament control director compiles data from other components of the armament control system to compute the course an aircraft must fly for its projectiles to strike a moving target.

When the director system (radar track) is used, all the necessary information is supplied by the radar set and the flight data unit. By its automatic tracking action, the antenna measures the direction and angular rate of the target. Present range to the target is also determined from the radar signals. The flight data unit supplies true airspeed and relative air density signals. From this information the armament control director can calculate the required lead angle.

The pilot receives flight direction information from the gun aim scope by the position of the aiming error dot. This dot is positioned by the armament control director and the pilot must maneuver the fighter to bring the dot to the intersection of the cross hairs. When this has been done, the fighter will be flying the correct lead-angle course on the target. The pilot need never see the target to attack and destroy it, and therefore can operate even under conditions of zero visibility.

Basically, this director or computer must perform three major computations:

1. Time of flight, which is the time required for the projectile to travel from the gun muzzle to the predicated or future position of the target.
2. Gravity deflection, which is the correction angle that compensates for deflection of the projectile by gravity.
3. Relative velocity lead angle, which is the angle that must be added vectorially to the gravity deflection angle to enable a projectile fired from one moving body to strike another moving body.

The basic function of the computer is to perform complex mathematical solutions, and all of its circuits carry intelligence in the form of functions of mathematical equations. These are actually precisely controlled voltages and currents.

Flight Data Computer

The function of the flight data unit is to supply airspeed, air pressure, and air temperature information. This information is needed by the armament control director for the solution of the fire control problem. Air temperature, static air pressure, and true airspeed are factors in computing relative air density. Recall from chapter 3 that air density will affect the amount of projectile deceleration caused by air resistance. The amount of deceleration will determine in part the time of flight—one of the major factors in the fire control problem. The factor, air density, is important in the aiming of both projectiles and rockets.

Within the flight data unit are climb and bank circuits, a true airspeed computer, and an altitude computer. These circuits and computers are supplied information by the aircraft's pitot-static system and vertical gyro. A thermometer within the flight data unit supplies an indication of air temperature directly to the computer. The climb and bank circuits supply to the armament control director a resolved gravity drop signal and to the radar climb and bank signals. The outputs of the true airspeed computer and the altitude computer are coupled to the armament control director which, in turn, produces a gravity drop signal for the climb and bank circuits in the flight data unit. As you can see, there is an interchange of information but essentially the flight data unit contributes needed information for the determination of the correct point of aim.

Purpose and Use of Controls

Many of the controls used with this type of ACS have been discussed earlier in this chapter. Therefore, we will briefly present the function of the controls for emphasis and to familiarize you with another system of control. You will recall that the qualifications for AQ3 state that you are responsible for energizing and securing fire control equipment plus setting operating controls. The following controls are shown in figure 6–21:

The ANTENNA POSITIONING LEVER moves in any direction to control the position of the antenna. In search operation, the forward and backward movement of this control positions the antenna scan in elevation. In track oper-

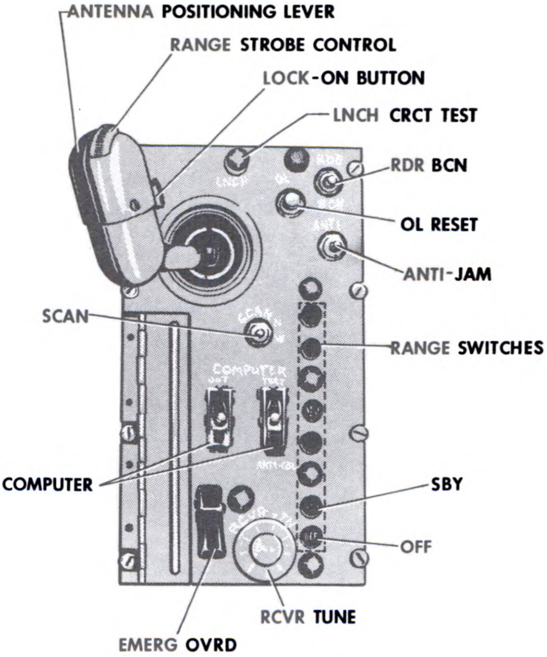


Figure 6–21.—Radar set operating controls.

ation, the lever determines the position the antenna will assume when the lock-on button is depressed to initiate automatic tracking. The position of the target select strobe on the B scope indicates the antenna position at the instant of lock-on.

The RANGE STROBE CONTROL is located in top forward portion of the antenna position lever. It controls the position of the range strobe (two parallel horizontal lines 1 mile apart) displayed on the B scope. When these lines straddle the target echo, the C scope immediately displays an echo of the same target.

The LOCK-ON BUTTON is located on the underside of the antenna position lever. It causes the system to begin automatic tracking of a selected target. To cease automatic tracking, the button is pressed and then released. Until lock-on occurs, the antenna can be positioned in azimuth by using the antenna positioning lever with the LOCK-ON trigger depressed.

The LNCH CRCT TEST is an indicator lamp which glows if the launch circuits are operating properly. It functions only when the COMPUTER switch is thrown to the TEST position. The OL RESET momentary-contact pushbutton switch is used to restore the high voltage circuits in the transmitting system when they open because of overload.

The RDR-BCN is a 2-position toggle switch which selects radar or beacon operation on the long ranges. The ANTIJAM OUT is also a 2-position toggle switch. In the ANTIJAM position it enables the pilot to separate two close targets, or to see targets through noise saturation. In the OUT position, targets are received without separation afforded by antijamming circuits.

The RANGE SWITCHES are pushbutton type of controls. Depressing any one of the range switches will put the equipment in full operation only after a 5-minute time delay. The SBY button is for standby operation and applies power to all tube heaters and all blowers. It is used to place the equipment in standby operation in radar silence zones, or when the equipment is not needed. After 2 minutes, full power is available to the complete system, with the exception of the high voltage stage which is protected by a 5-minute time delay to allow the last stage to reach proper operating temperature.

The RCVR TUNE control is both a rotary switch and a variable control. Turned fully clockwise, the switch places the equipment under automatic frequency control. The numbers appearing on the control are used for manual tuning of the receiver. The EMERG OVRD is a 2-position toggle switch which is used in an emergency to override all protective circuits which cause the radar to cease operation. Both COMPUTER controls are 3-position toggle switches used in the alining and testing of the computer. The SCAN switch selects either narrow or wide scan pattern for the antenna.

The next group of controls will be found on the indicator

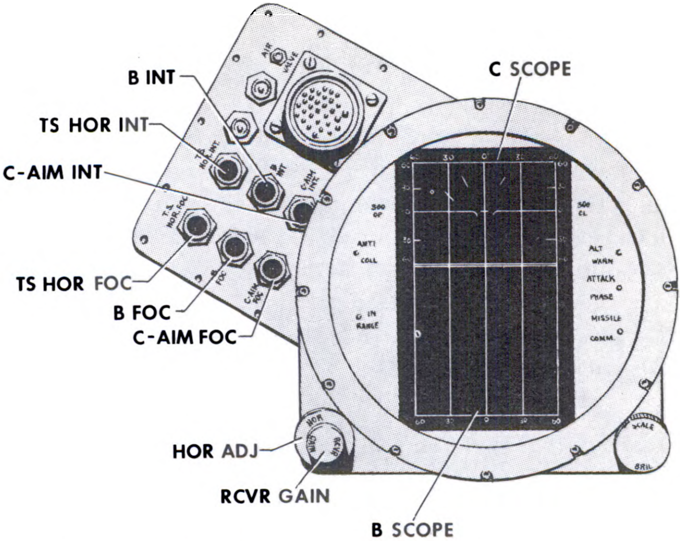


Figure 6–22.—Operating controls for radar indicator.

shown in figure 6–22. The SCALE BRIL control is used to adjust the scale brilliance on the B and C scopes. The RCVR GAIN adjusts the sensitivity of the receiver while the HOR-ADJ controls the vertical position of the artificial horizon. The C-AIM FOC adjusts the focus of the C-scope presentation while the B-FOC adjusts the focus of the B-scope presentation. The TS HOR FOC controls the focus of the target select strobe and the artificial horizon line and their intensity is adjusted by the TS HOR INT. The B-INT and the C-AIM INT adjust the intensity of the B-scope and C-scope presentations.

MISSILE GUIDANCE SYSTEM

The fourth and final type of armament control system in our discussion is one capable of controlling certain types of guided missiles. Usually in the overall operation of this system, the interceptor is vectored by directions from the aircraft carrier to intercept the target. The pilot of the interceptor optically acquires the target and then maneuvers for a prescribed attack.

When the target comes within a predetermined range, the radar locks-on the target and indicates this lock-on to the pilot. The pilot then has the means of checking whether or not the radar is locked-on the desired target. The radar computes an area of optimum launching range on the basis of the closing speed of the aircraft with the target. When the range to the target becomes optimum, the information is relayed to the pilot. This information signal continues as long as the range lies within the optimum area.

While this range warning signal is energized and the aircraft is in a prescribed attitude, the pilot launches a missile by pressing the firing button on the control stick. For a short period of time after the missile is launched, it is propelled by its rocket motor. This is called the PROPULSION PHASE. During this period the missile is not guided, but maintains an approximately straight and level course because of its stabilization system.

At the end of the period of powered flight, the missile is well out ahead of the aircraft in the radar beam, and the period of guided flight begins. The receiver in the missile picks up guidance signals that are transmitted between tracking pulses. The missile maneuvers to fly at the center of the beam; that is, it is "captured" by the beam as shown in figure 6–23. As the radar beam moves to follow the target, the missile adjusts its flight path to remain in the center of the beam. This results in an intercept or collision course with the target.

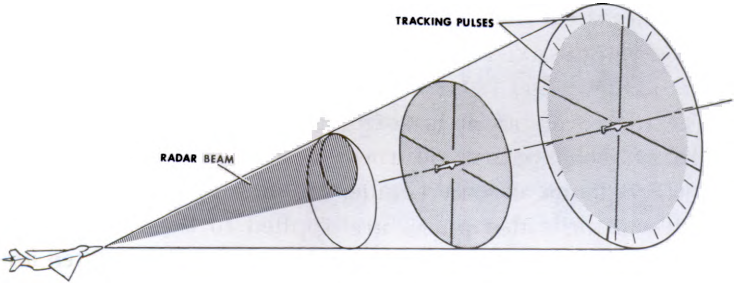


Figure 6–23.—Guidance of missile by radar beam.

The missile warhead contains an explosive charge which is set off by a proximity fuze when the missile passes within effective range of the target. If the missile is not captured by the radar beam or if, after it has been captured, the guidance pulses are lost, as when the beam moves faster than the missile can follow, the missile automatically detonates and destroys itself, removing its danger to friendly aircraft.

Block Diagram

The block diagram for the radar of this type of ACS is shown in figure 6–24. The diagram does not contain a block for the AFCS but an arrow indicates where the range voltage goes to the gunsight. It should be stated that while our discussion is centered around the missile guidance features of this armament control system, it also can be used to determine the required lead angle for both guns and rockets.

Utilizing the block diagram of figure 6–24, let us trace the overall system operation. The synchronizing circuits generate the trigger pulses which eventually fire the magnetron (final transmitting tube). The magnetron develops the microwave pulses that are propagated from the antenna in a pencil beam. When the radar beam intercepts a target, echo pulses are reflected back to the antenna and applied to a conventional radar receiver. Because of the conical scan pattern produced by antenna nutation, the target echo pulses vary in signal strength at a rate determined by the nutation of the antenna. By nutation is meant that the center of the pencil beam is caused by eccentric gears to describe a circle offset from the axis of the cone. Figure 6–25 shows how the beam axis is offset from the cone axis and thus the beam, as it rotates, covers an area within a larger circle.

Target echo pulses, returned to the receiver-transmitter via the antenna and waveguide, are amplified and detected. The resulting video pulses are applied to the radar range circuits. Due to the conical scan formed by the nutated antenna, the video pulses have a variation in signal strength called SPIN MODULATION.

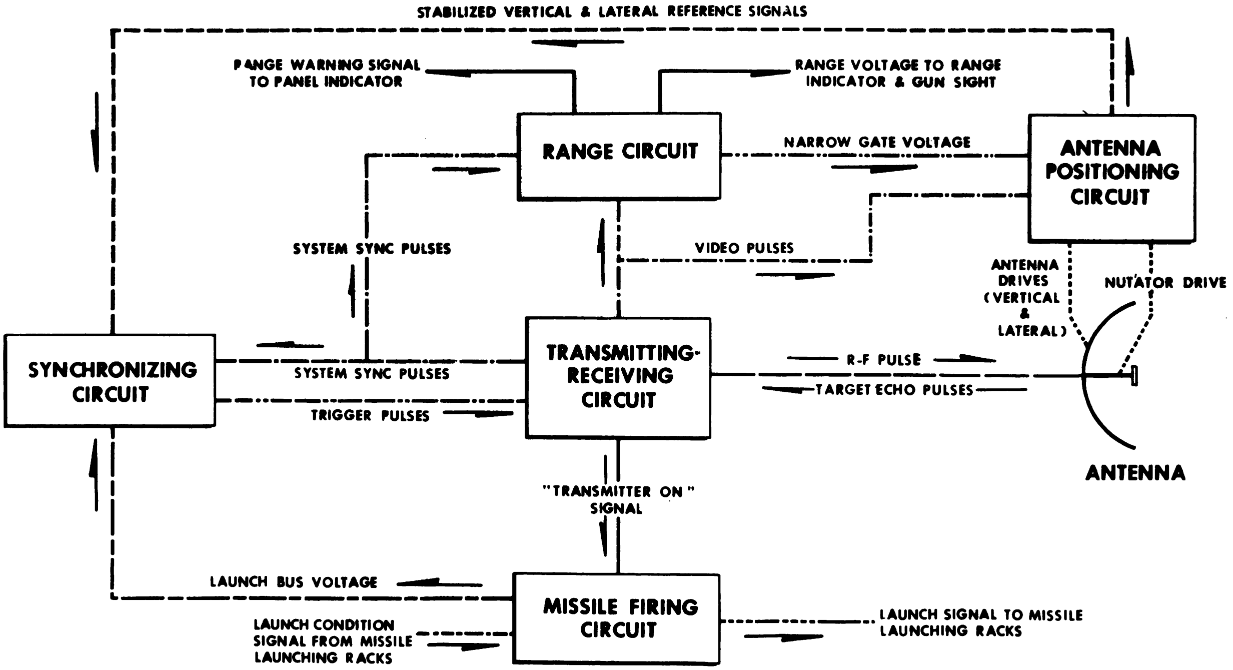

STABILIZED VERTICAL & LATERAL REFERENCE SIGNALS
RANGE WARNING SIGNAL TO PANEL INDICATOR
RANGE VOLTAGE TO RANGE INDICATOR & GUN SIGHT
RANGE CIRCUIT
NARROW GATE VOLTAGE
ANTENNA POSITIONING CIRCUIT
SYSTEM SYNC PULSES
VIDEO PULSES
ANTENNA DRIVES (VERTICAL & LATERAL)
NUTATOR DRIVE
SYNCHRONIZING CIRCUIT
SYSTEM SYNC PULSES
TRIGGER PULSES
TRANSMITTING-RECEIVING CIRCUIT
R-F PULSE
TARGET ECHO PULSES
ANTENNA
"TRANSMITTER ON" SIGNAL
LAUNCH BUS VOLTAGE
MISSILE FIRING CIRCUIT
LAUNCH CONDITION SIGNAL FROM MISSILE LAUNCHING RACKS
LAUNCH SIGNAL TO MISSILE LAUNCHING RACKS

Figure 6—24.—Block diagram of a missile guidance radar.

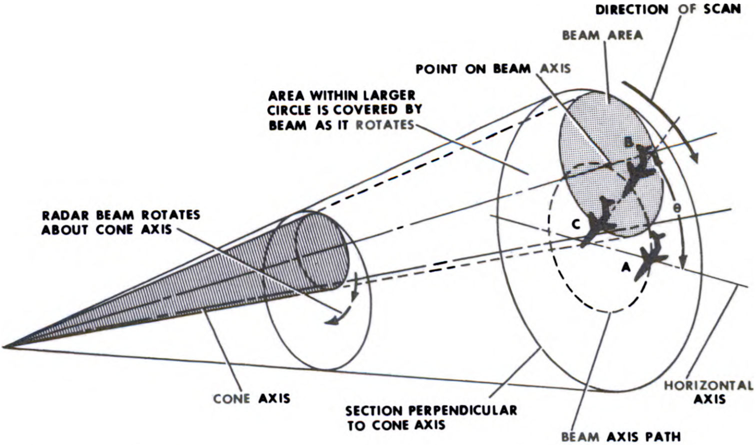

DIRECTION OF SCAN
BEAM AREA
POINT ON BEAM AXIS
AREA WITHIN LARGER CIRCLE IS COVERED BY BEAM AS IT ROTATES
RADAR BEAM ROTATES ABOUT CONE AXIS
B
C
A
θ
CONE AXIS
SECTION PERPENDICULAR TO CONE AXIS
BEAM AXIS PATH
HORIZONTAL AXIS

Figure 6–25.—Conical scan pattern produced by nutation of the antenna.

The system's synchronization (sync) pulses coincide with the magnetron trigger pulses and are applied to the synchronizing and range circuits. (See fig. 6–24.) These sync pulses establish the exact time of the transmitter output pulse and permit accurate timing of the guidance pulses. In the range circuit section, the sync pulses start the range sweep. Also, the range circuits produce a signal called "the narrow gate voltage." This signal is established by comparing the range sweep voltage and a voltage proportional to range. This "narrow gate voltage" is then applied to the antenna positioning circuit. (See fig. 6–24.) The purpose of the narrow gate is to lock-on and track the target.

In track operation of this ACS, before a target is acquired, the radar range section automatically searches in range with the antenna held in the boresighted position; i. e., alined with the optical sight. When a target comes within the "narrow gate," the range search stops and the spin modulated target echo pulses are automatically tracked in range. Also the spin modulation error signal on the target echo furnishes the information to control the antenna both vertically and laterally. Thus, the antenna automatically follows the target. The antenna positioning circuits also feed a stabilized vertical and lateral reference signal to the synchronizing section for use in developing the guidance pulse.

When the target is tracked within a computed optimum launch range, the range warning signal is developed. The pilot can release his missile by pressing the firing button on the control stick. If all the prefiring conditions are satisfied (wheels retracked, radar transmitter on, and master armament control switch on), the launch bus is energized. This will complete another triggering circuit, which may be considered trigger 2 to separate it from the tracking trigger pulse. This second trigger pulse initiates the missile guidance pulses. At the same time, the missile's and aircraft's gyroscopes are uncaged, and the missile rocket motor is ignited. The gyroscopes maintain a stable reference frame during the missile time of flight.

The axis of the conical scan described by the radar beam axis, when tracking the target, provides a sight line route to the target for the missile. The entire system must provide a method of controlling the missile so that it will fly along this automatically maintained path; that is, ride the beam as shown in figure 6–23. In order to accomplish that, it is necessary that the missile be able to sense when it is on the nutating beam axis. Furthermore, when the missile is displaced, it must know the direction and degree of displacement.

If both missile and aircraft have a common gyroscopic reference, the problem then is to inform the missile when it leaves the sight line between antenna and target. This is accomplished by use of guidance pulses or signals. Essentially this consists of sending a "turn left" signal when the radar beam sweeps through the right section of the cone pattern, and a "turn right" signal when the beam sweeps through the left horizontal axis. Similar signals are dispatched for "turn up" and "turn down" directions. These directions are synchronized with the antenna's nutation.

When the missile is on the cone axis (fig. 6–23), all turn signals balance, and the missile continues its flight without correction. If the missile is displaced from the cone axis, one signal overbalances the other; this stronger signal turns the missile back toward the axis of the nutating beam.

Therefore, the radar transmitter must provide a regular tracking pulse and a guidance pulse. These guidance pulses are received by the missile and are identified in the missile by their time sequence. Once separated within the missile receiver, the guidance pulses control the direction of flight of the "bird."

Before launching, the radar provides just the tracking pulses. When the launch bus or circuit is energized (fig. 6–24) by the firing button, the circuits which provide the guidance pulses are also energized. Such a guidance system is dependent upon the control system of the radar and the missile maintaining a stable reference frame. This is to prevent such occurrences as "up" signals resulting in a downward flight of the missile. In this system a stable reference frame is provided by the gyroscopes in both the aircraft and the missile being uncaged simultaneously at the time of launching.

Thus when the pilot presses the firing button, the following events occur: The roll reference gyro in the missile is uncaged, the external filament power is cut off, and the missile battery power supply is turned on. A signal is fed back to the aircraft when this has been done. The direction free gyro of the aircraft is then uncaged and power to the gyros is cut off so that both gyros coast during the brief flight of the missile. As soon as the signal that this has occurred reaches the aircraft, the rocket motor is fired, the umbilical connection is cast off, and the missile is on its way.

Purpose and Use of the Controls

The radar set controls shown in figure 6–26 have the following functions: (1) To provide for the selection of the operating mode, (2) to provide for momentary manual control of the range search circuit to facilitate resetting the range sweep to minimum range or to cause the range sweep to unlock and continue past an undesired target, (3) to pro-

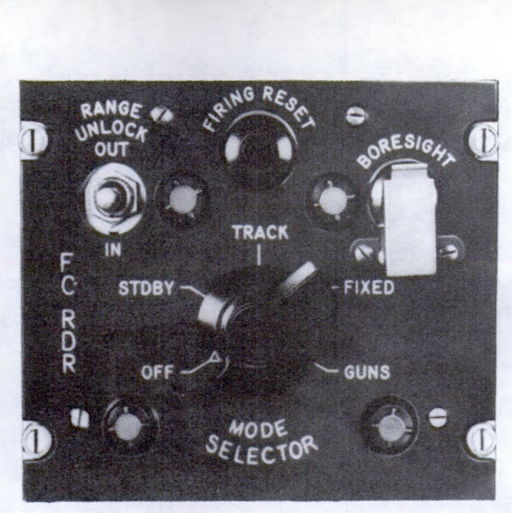


Figure 6–26.—Radar control box.

vide for establishing the antenna boresight reference to be used during FIXED mode operation, and (4) to provide for emergency resetting of the firing circuit to initial conditions after a missile has been launched.

The RANGE UNLOCK switch is used to move the radar range gate in or out in range. The IN position reduces the range gate to the minimum range, while the OUT position increases the range gate in range. When the switch is released in either of these positions, it returns to the center position by spring action. In the center position, the switch has no affect on the range gate. This switch, then, is used to unlock the range gate from the wrong target and to move it in or out to the correct target.

The FIRING RESET button is used to restore the equipment to prefiring conditions in emergencies. When this button is depressed, it cages the gyro, stops the guidance signals, unarms the missiles in the racks, and destroys the missile in flight. This switch, then, is used to destroy a missile before completion of its flight. It can also be used to prepare the equipment to fire a second missile if the first missile has hit or missed the target in an extremely short period of time.

The BORESIGHT button is used to aline the antenna with the optical sight. When this switch is depressed the antenna tracks the target in the optical sight. When released, it stores the antenna in a position prescribed by a "memory" circuit. This switch is used before every attack run to correct any misalinement of the optical sight and antenna zero position. It is possible to make this alinement on either friendly or hostile aircraft.

The MODE SELECTOR switch is used to control progressive distribution of power to various components, and to select the mode of operation and type of weapon to be fired. In the OFF position, it deenergizes all components. In STDBY position, it energizes all components except the radar transmitter high voltage circuits, and commences the 5-minute time delay.

The TRACK position energizes all components and the radar antenna can follow a target on which it has locked. This position is used for normal air-to-air missile attack. The FIXED position energizes all components, but the antenna remains fixed along the optical line of sight. This position is used to pick one air target out of a formation, to pick a ground target out of a complex target, to track a low flying target. or to optically select a portion of a larger target. The GUNS position of this switch feed range voltage to the gun fire control system. As its name implies, it is used for gunfire attacks.

Maintenance

The maintenance principles presented under the previously discussed armament control system also generally apply to this system. It is highly probable that as an AQ3 the extent of your maintenance work on this complex type of ACS will consist of checking for correct operation and assisting a higher rated technician. It is appropriate though, to point out that for you to intelligently assist other technicians and to perform a thorough operational check requires a knowledge of the overall operation of the equipment and the application of sound maintenance techniques.

QUIZ

1. The typical armament control system is a complete system for
   - a. computing range
   - b. computing lead angle
   - c. computing range rate
   - d. supplying target information to a gunsight
2. The components used in an armament control system are furnished by the Bureau of Aeronautics and the Bureau of
   - a. Ships
   - b. Personnel
   - c. Ordnance
   - d. Supplies and Accounts
3. The range computer used with the ARO radar and AFCS Mk 6 system generates a d-c voltage that is proportional to the
   - a. lead angle between aircraft and target
   - b. speed of the aircraft
   - c. speed of the target
   - d. distance between the aircraft and the target
4. In the ARO radar and AFCS Mk 16 system, the function of the radar is to provide
   - a. manual ranging
   - b. automatic lead angle
   - c. automatic ranging
   - d. target video to an indicator
5. In the ARO radar and AFCS Mk 16 system installed in an aircraft, the actual solution of the fire control problem is accomplished by the
   - a. ARO radar
   - b. AFCS Mk 16
   - c. pilot
   - d. range computer
6. The majority of maintenance on an ARO radar and AFCS system performed by an AQ3 will be
   - a. on the AFCS portion
   - b. on the ARO radar portion
   - c. on the ARO radar portion under supervision
   - d. equally distributed between the two

7. In the combination optical and radar armament control system, the sighting information is presented to the pilot
   a. by means of a radarscope only
   b. visually by a movable reticle image only
   c. by means of a radarscope and visually by a moving reticle image
   d. course path cross hairs
8. In the optical and radar armament control system the radar has three modes of operation. During which mode of operation is lock-on initiated?
   a. Automatic search
   b. Manual search
   c. Automatic track
   d. Manual track
9. In the automatic track mode of operation, the antenna
   a. is locked on the target
   b. remains alined with the aircraft
   c. continues to sweep automatically
   d. can be moved manually
10. In the automatic track mode of operation, range information is displayed on the radarscope
   a. on the range trace
   b. by means of the range gate marker
   c. by a range circle
   d. by means of the artificial horizon
11. In a typical fire control radar, the synchronizing section
   a. generates high power RF pulses at a rate which is timed by the master trigger pulses
   b. generates the trigger pulses for timing the operation of the entire system
   c. generates the search and attack displays presented on the radarscope
   d. receives target echo and beacon signals from the RF section
12. In a typical fire control radar, the range-tracking section accepts the master trigger and tracked-video echo signals as input information and furnishes as output a signal that is
   a. proportional to range
   b. proportional to size of target
   c. displayed on the range trace
   d. proportional to the number of targets

13. The purpose of space stabilization is to
    a. keep the target stabilized in range
    b. prevent the pattern from being affected by the roll and pitch of the aircraft
    c. compensate for aircraft altitude
    d. prevent the target from becoming lost while in automatic track

14. In the typical optical and radar ACS, the function of the AFCS is to
    a. provide range information to the system
    b. provide ballistic and kinematic information to the system
    c. provide compensation for roll and pitch to the system
    d. prevent the guns from firing until the target is within range

15. In the typical optical and radar ACS, the master switch provides a warmup period for the equipment when it is in
    a. STANDBY position only
    b. STANDBY and OPERATE position
    c. OPERATE position only
    d. EMERGENCY position

16. The function of the antenna hand control in the optical and radar ACS is to
    a. control the antenna's azimuth position during automatic search operation
    b. control the position of the antenna in azimuth and elevation during manual search operation
    c. control the position of the antenna in azimuth and elevation during automatic track operation
    d. keep the antenna stabilized in all modes of operation

17. The receiver gain control in a typical radar ACS adjusts the intensity of targets on the scope during
    a. automatic track operation only
    b. automatic track and search operations
    c. manual and automatic search operation
    d. automatic search operation only

18. The auxiliary attack intensity control in a typical radar ACS should be adjusted with the attack intensity control fully counterclockwise so that the flight indicator
    a. attack display barely disappears with the indicator well shaded
    b. attack display is plainly visible in bright daylight
    c. attack display is a sharply defined display
    d. will have targets on the attack display

19. A nonoptical radar ACS is one in which the detection of the fire control problem takes place within the
    a. AFCS
    b. AFCS computer
    c. radar and AFCS computer
    d. radar and associated electronic equipment
20. In a typical nonoptical radar ACS, the receiving system employs two local oscillators. One is used in detecting the radar signal, the other is called the
    a. beacon local oscillator
    b. radar local oscillator
    c. IF local oscillator
    d. indicator local oscillator
21. During automatic tracking, the B scope of a typical nonoptical radar ACS system presents
    a. a range rate circle and target dot
    b. an artificial horizon line
    c. range and azimuth information of the target selected for tracking
    d. azimuth and elevation information of the target selected for tracking
22. The armament control director in a typical nonoptical radar ACS must perform what three major computations?
    a. Time of flight, gravity, and relative velocity lead angle
    b. Range, angular rate, and time of flight
    c. Present range, true airspeed, and relative air density
    d. Air temperature, gravity, and true airspeed
23. When a guided missile is launched from an aircraft, the missile guidance system takes over the direction of the missile
    a. as soon as the pilot optically acquires the target
    b. as soon as the target range becomes optimum
    c. at the end of the stabilization period
    d. when the missile passes within the effective (proximity) range of target
24. The conical scan pattern for missile guidance is developed by
    a. spin modulation
    b. range lock-on
    c. nutation of the antenna
    d. rotation of the antenna
25. Spin modulation is used within the guidance radar to
    a. lock-on the target in range
    b. track the target in azimuth and elevation
    c. guide the missile during thrust phase
    d. develope the narrow gate

26. The reason a missile does not fly down when receiving an up signal or fly left when receiving a right signal is due to

- a. gyros within the missile maintaining earth stabilization
- b. gyros within the missile and radar maintaining a stable reference frame
- c. radar tracking the missile
- d. a boresight reference stored within the missile

CHAPTER 7

AIRCRAFT TURRET CONTROL

The development of aircraft turret control systems has kept abreast of the systems used in controlling forward firing guns. In the preceding chapter we have traced the development of forward firing control systems from purely optical, optical and ARO radar, to purely electronic. This chapter, will treat the systems for control of aircraft turrets in like manner.

The Mk 18 gunsight is fundamentally an optical system, and will be discussed in this chapter. A later modification of the Mk 18 (the Mk 18 Mod 10) is the addition of the AN/APG 30A ARO radar. The system retains all of the Mk 18 gunsights operating features, including manual ranging (for emergency use) with the addition of automatic radar ranging.

In this chapter the optical/ARO radar system need not be discussed since the Mk 18 is altered little and ARO radar has previously been discussed. Thus, after discussion of the Mk 18 gunsight (optical system), we will investigate an electronic all-weather system.

OPTICAL SIGHT SYSTEM (MK 18)

Principles of Operation

The Gunsight Mk 18 Mod 6 (fig. 7–1) is a LEAD-COMPUTING reflector-type sight combined with a FIXED reflector-type sight. It is used to compute and indicate the point of aim for either .50-cal. or 20-mm turret guns. As pointed out in chapter 4, the Mk 18 gunsight was the forerunner of the Aircraft Fire Control System Mk 6. Therefore, as we shall see, there are many similarities between the two.

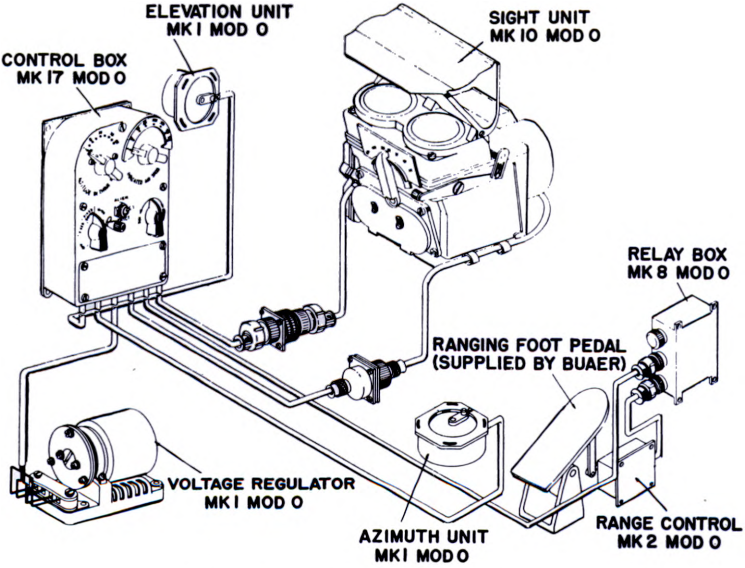


Figure 7–1.—Gunsight Mk 18 Mod 6.

In this gunsight, the lead computing is accomplished by use of an electromagnetically controlled gyroscope. The point of aim is displayed to the gunner as a deflection between a fixed image and a movable image. As in the AFCS, the movement is obtained by tilting a gyro mirror.

The target is viewed by the gunner through a clear glass reflector plate on which is reflected the images of two reticle patterns. These two patterns are projected by two similar optical systems, focused at infinity, which causes them to ap-

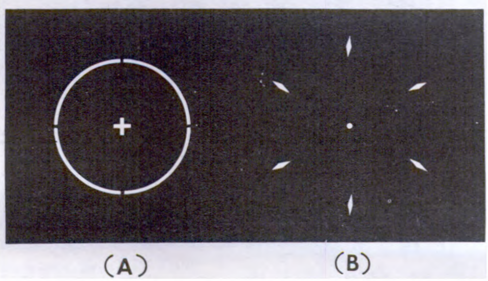


Figure 7–2.—Reticle image patterns.

pear to be superimposed on the target. The circle and cross reticle image ((A) of fig. 7–2) seen by the left eye, is referred to as the "fixed image." The cross of the fixed image establishes a fixed sight line which indicates the direction the guns are pointing.

The gyro or movable image ((B) of fig. 7–2), seen by the right eye, is composed of six diamond-shaped dots arranged in a radial pattern, with a round dot in the center. This pattern is referred to as the "lead-computer image" or "gyro image." By using this image, the gunner's problem is simplified to that of setting the known or estimated dimension of the target into the sight by means of the scale pointer. He then keeps the target framed within the diamond-shaped

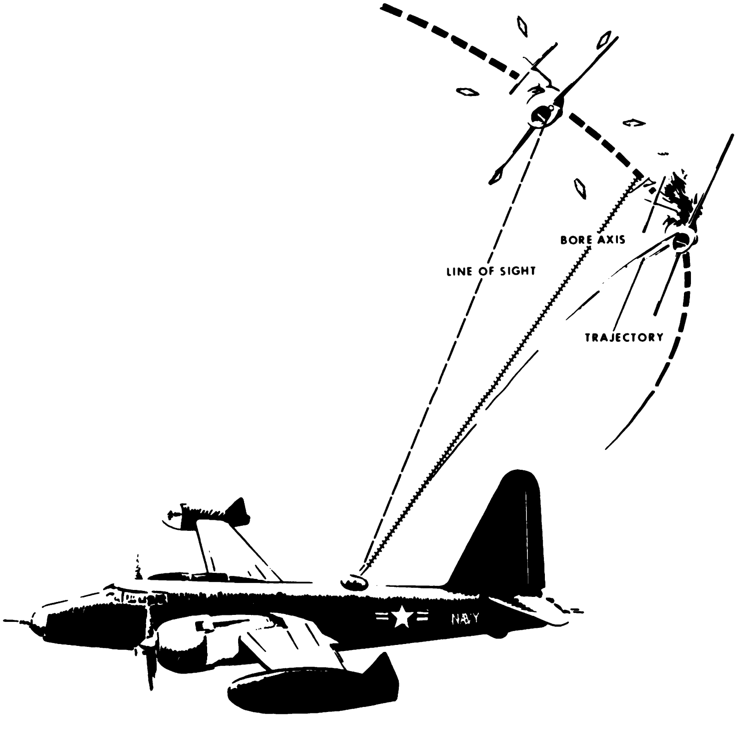


Figure 7–3.—Indication of lead.

dots by continuously varying the diameter of the circle by means of a foot pedal control.

The gunner's objective is to bring the center pip of the GYRO pattern to bear on the target and to keep the target properly framed as it comes within range and while it is being fired upon. While tracking the target, the gyro image lags behind the fixed image, automatically establishing the proper lead angle. This is true provided the gunner has set into the controls the correct values of altitude and indicated airspeed for his aircraft and that he smoothly tracks and accurately frames his target.

Thus the sight will automatically compute and compensate for the following factors: (1) Relative target motion, (2) time of flight of the bullet, (3) windage, and (4) gravity drop. By automatically allowing for these factors, this sight relieves the gunner of the necessity of estimating lead and permits him to concentrate on the mechanical operation of this turret. The relationship between the line of sight, bore axis, and trajectory is shown in figure 7–3.

Block Diagram

Using the block diagram in figure 7–4, let us now trace the information flow in the system and how the gunsight solves for the correct lead angle. You will recall we stated in chapter 3 that the angle of lead required to hit a target is equal to the relative angular velocity of the target multiplied by the time of flight of the bullet to the target.

The first of these factors (relative angular velocity) is determined in the gyro unit. When the gunner tracks his target at a certain angular velocity, the gyro, trying in true gyroscopic manner to maintain its direction fixed in space, lags behind the gunner's tracking. It lags by an angle equal to the angular velocity of tracking. This angular lag produces a precessing torque (turning force) which produces a rate of precession (gyro movement) equal to the gunner's tracking.

Besides the tracking rate, the amount of this gyro lag is controlled, in part, by the magnetic field strength in which

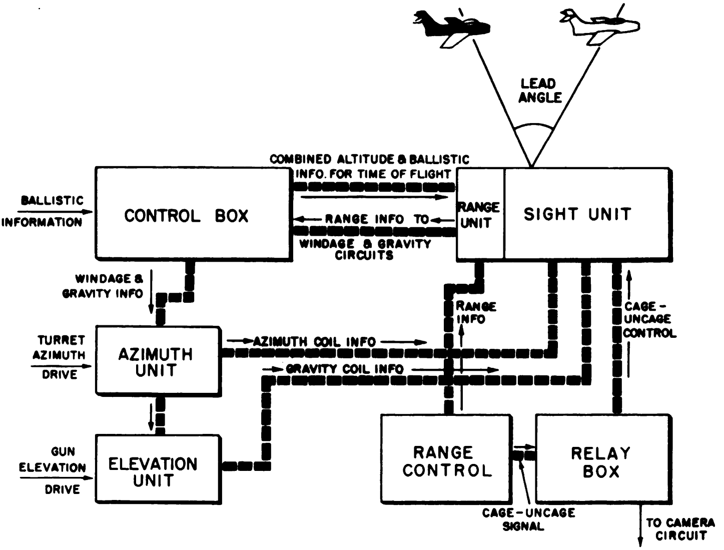


Figure 7–4.—Block diagram of Gunsight Mk 18 Mod 6.

the gyro's aluminum dome is spinning. The field strength, in turn, is determined by the amount of current in the range coils which produce the magnetic field. This coil current is delivered by a range and altitude controlled network which, in effect, makes the lag proportional to the bullet's time of flight to the target. This lag of the gyro axis behind the gunner's tracking is communicated by the tilting gyro mirror to the gyro optical system as a lag of the gyro image behind the fixed image.

From this we can see that the system must produce, in the range coils, a current equivalent to the time of flight. The actual time-of-flight circuit is a series-parallel resistance network that receives a regulated d-c power input. This voltage is modified by the following resistors: (1) Either a .50-cal. or 20-mm ballistic resistor, (2) a variable altitude resistor of the altitude control, and (3) a variable range time-of-flight resistor of the range unit. Therefore, by using these resistors, the ballistic information is combined with altitude in the control box. (See fig. 7–4.) Then the combined information is further coordinated with the range datum in the range unit and thus used to control the current in the range coils, thereby conveying the time-of-flight information to the gyro. The gyro then serves as the final computer combining time of flight and relative angular velocity. Incidentally, this range circuit is also corrected for changes in sight unit temperature.

TRAIL OFFSETS.—Trail offsets are allowances for windage and gravity. The magnetic field of the gyro is also influenced by the azimuth, elevation, and gravity coils. The azimuth coil causes a horizontal shift of the CENTER of the magnetic field but does NOT affect the total strength. The elevation trail and gravity coils act similarly; both produce vertical shifts of the magnetic field center.

Since the gyro axis always tends to aline itself through the center of the magnetic field, corrections for windage and gravity effects can be superimposed upon the kinematic lead computation merely by varying the currents in the azimuth, elevation, and gravity coils. These coil currents are properly varied by means of an electrical resistance network containing controls for range, altitude, indicated airspeed, gun azimuth and gun elevation.

The trail circuit in this gunsight has two section; namely, a windage section and a gravity section. A portion of this circuit is common to both sections inasmuch as target range and ballistic properties of the projectiles are used to affect both windage and gravity allowances.

The windage section is a divider type resistance network with both an azimuth and an elevation output. The resistance network determines the amount of current flowing in both azimuth and elevation coils which, in turn, influence the gyro. In this windage circuit the current is determined by (1) a variable range resistor of the range unit, (2) either of two fixed ballistic resistors (3) a variable resistor of the altitude control, (4) a variable resistor of the airspeed control, and (5) the resistance of the azimuth unit. The resistance network then combines the range, ballistic, altitude, airspeed, and gun azimuth information respectively in the determination of the current flowing in the azimuth trail coil. The elevation trail coil current is determined by the information from the azimuth unit being fed to the gun elevation unit and then to the elevation coil. (See fig. 7–4.)

The gravity section of the trail circuit is also a resistor network. The gravity coil current is determined by (1) a variable range resistor, (2) a fixed ballistic resistor (either .50-cal. or 20-mm), and (3) the resistance of the elevation unit. Notice that the gravity current is independent of the altitude, airspeed, and the azimuth unit.

Thus, we can summarize the computing or information networks as:

1. Range coil current or information depends on range, altitude, ballistic properties of the projectile, and sight unit temperature.
2. Azimuth coil current depends on range, altitude, airspeed, gun azimuth, and ballistic properties of the projectile.
3. Elevation coil current depends upon range, altitude, airspeed, gun azimuth, gun elevation, and ballistic properties of the projectile.
4. Gravity coil current depends on range, gun elevation, and ballistic properties of the projectile.
5. Thus, the range coil current determines the strength of the magnetic field; and the trail and gravity coil current, in relation to the range coil current, determines the effective center.

CAGING CIRCUIT.—The caging circuit (fig. 7–4) consists of the means needed to cage or uncage the gyro. By releasing the ranging foot pedal (maximum range), the caging signal is sent to the relay box. Here a relay is energized which results in a large amount of current flowing through the range coil, thereby caging the gyro. This uncage-cage signal can also be used to activate or deactivate a camera circuit.

Components and Functional Operation

The major components of Gunsight Mk 18 Mod 6 are shown in figure 7–1. Let us now considere each of these components and how they contribute to the functional operation of this equipment.

Sight unit.—The sight unit consists of three components—the housing assembly, the gyro, and the range unit. The housing assembly contains two similar collimated optical sighting systems in a gasket-sealed housing mounted on an antivibration mounting system. The purpose of this mounting system is to protect the entire unit from dangerous shock due to gun recoil.

As shown by figure 7–5, the images of the two reticle patterns are projected, one onto the fixed mirror, the other onto the gyro tilting mirror. Both are then reflected to the front mirror. The front mirror, in turn, effects both images through twin collimating lenses to an inclined clear glass plate that reflects both images to the eyes of the gunner.

A study of figure 7–5 will reveal that this system is the same, with one minor difference, to that used in AFCS Mk 6. Not only are the optical systems the same but also the gyro units. The minor difference in this optical system is the pattern of the fixed reticle. Therefore, for the functional operation of the optical system and the gyro unit refer to chapter 5.

The third component of the sight unit is the range unit which is attached to the left-hand side of the sight housing. The range unit contains two potentiometers (ballistic and servo response), a constant speed motor, two electromagnetically operated reversing clutches, a brake assembly, and the necessary gear train.

The ballistic potentiometer has two wire wound resistance windings; the resistance value of these windings is controlled by the range setting. One of these windings controls the ballistic computer time-of-flight circuit that feeds the gyro range coils; the other winding controls the windage and gravity circuit that feeds the azimuth, elevation, and gravity coils. The temperature compensating unit is also connected to the ballistic potentiometer to compensate for errors introduced in the electrical circuits by changes in the sight operating temperature.

The servo response potentiometer is connected to a servo control potentiometer in the range control to form a Wheat-

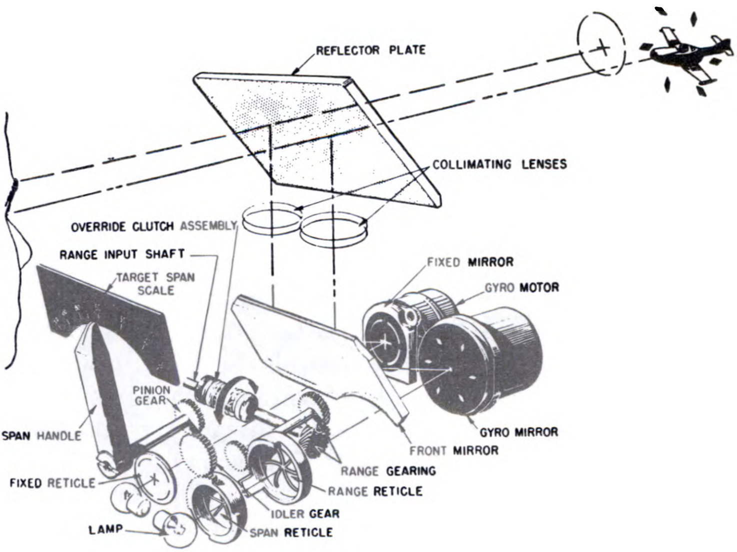


Figure 7–5.—Sight optical system.

stone bridge circuit. This bridge in conjunction with the motor, clutches, brake, and gear train comprise a servo system. The servo system relays range information from the range control to the range unit. Thus a change in the range setting of the range control results in varying the diameter of the gyro reticle image. It also changes the range ballistic potentiometer that controls the lead, windage, and gravity allowances.

Range control.—The range control contains the servo control potentiometer, a gear and cam assembly, and a cam operated caging switch. The gunner controls the range setting in the gunsight by rotating the input shaft of the range control by means of a foot pedal and linkage. When the input shaft travels beyond the position corresponding to maximum range setting (foot pedal fully raised), the caging switch is closed. By closing this switch, the power supply is connected to the caging circuit and opens the camera control circuit.

Relay box.—The relay box is usually mounted in any convenient location in the turret and requires no attention by the gunner. This box contains the electrical equipment that controls the ranging servomechanism, the gyro caging circuit, and the recorder camera control circuit.

CONTROL BOX.—The control box is usually mounted within easy reach of the gunner and contains the controls necessary for operation of the equipment. A fuller discussion encompassing the purpose of each control will be presented in the next section on operating controls.

AZIMUTH UNIT.—The azimuth unit is mounted in the turret and geared to the azimuthal motion of the turret so that it requires no presetting or other attention by the gunner. This unit automatically controls the azimuth windage allowance in accordance with the position of the turret. Control is accomplished by the use of a divider-type resistance network. The block diagram (fig. 7–4) shows that the input information comes from the control box. This information is the windage circuit current and has been modified for range, ballistics, altitude, and airspeed. The azimuth unit separates the windage current into azimuth and elevation components, and passes the resultant currents to the azimuth coils and the elevation unit.

When the gunner fires at 90 degrees right or left of the bow, the windage deflection is entirely an azimuth component and has no elevation component; therefore, at 90 and 270 degrees azimuth, this control delivers maximum current to the azimuth coils and zero current to the elevation unit. However, if the gunner fires directly ahead or aft, his bullets are not deflected laterally, though they will be deflected in elevation if he elevates or depresses his line of fire. Hence, for these fore-and-aft positions, the azimuth control delivers zero current to the azimuth coils and maximum current to the elevation unit. In the intermediate position, this control delivers intermediate amounts of current to both the azimuth coils and the elevation unit.

Since the correction of azimuth windage reverses when the guns are moved from the portside to the starboard side, a reversing switch is incorporated to reverse the polarity of the azimuth output at zero and 180 degrees azimuth.

Because, relative to the line of sight, the elevation windage correction appears to reverse when the guns are moved from the forward area to the aft area, a reversing switch is incorporated to reverse the polarity of the elevation output at 90 and 270 degrees azimuth.

ELEVATION UNIT.—The elevation unit consists of two separated controls operated by the crank that is geared to the gun elevation drive: An elevation divider and a gravity coil shunt. The elevation unit, then, is geared to detect the vertical movement of the guns.

The elevation divider consists of two variable resistors connected in the windage circuit. This divider receives current from the elevation output of the azimuth unit, properly modifies it with respect to elevation, and passes it to the elevation coils. This modification consists, essentially, of passing zero current at zero elevation, maximum current at maximum elevation or depression, and intermediate amounts of current at intermediate positions.

Because the elevation windage effect reverses direction when the guns are moved from the upper hemisphere to the lower hemisphere, a reversing switch is incorporated to reverse the polarity of the output at zero gun elevation.

The gravity coil shunt is a variable resistor connected across the gravity coils to modify the current with respect to gun elevation. Gravity produces no deflections of the gunner's bullets when he fires vertically upward or downward, but produces maximum deflections when he fires in a horizontal plane. Therefore, the resistance is varied so as to allow maximum current to flow in the gravity coils at zero elevation, zero current at maximum degrees elevation or depression, and intermediate amounts of current at intermediate positions of elevation or depression.

VOLTAGE REGULATOR.—The purpose of the voltage regulator is to compensate for fluctuations in the aircraft's 28-volt d-c power and the equipment's current drain, so as to supply a constant 22-volt d-c power to the sight lamps, the gyro motor and coils, and the ballistic computer. The voltage regulator is mounted in any convenient location in the turret.

Operating Controls

The operating controls for Gunsight Mk 18 Mod 6 are on the control box, the sight unit, and the range control. Let us now consider each of these in turn and the function of each control.

Control box controls.—The controls of the control box are shown in figure 7–6. The ALTITUDE CONTROL is set to the aircraft's indicated altitude by the gunner before ranging and tracking. This control by varying three resistors inserts the correct altitude information into the computing circuits. One of these resistors is connected in the time-of-flight circuit while the other pair of resistors is connected in the windage network. As shown in figure 7–6, the scale indicates thousands of feet graduated in 5,000-foot increments. The pointer positions are friction secured, and rotation of the pointer is restricted at the limits of the scale by stops.

The INDICATED AIR SPEED control must also be set by the gunner to the aircraft's indicated airspeed. This control, by varying the value of two resistors connected in the windage network, adds the airspeed information to the solution of the correct point of aim. This control actually receives current from the altitude divider and modifies the current to the azimuth and elevation divider network, so that windage allowances increase with increased airspeed of the aircraft. As shown in figure 7–6, the scale is graduated and numbered in 50-knot increments. The pointer positions are friction secured; stops at the limits of the scale restrict the pointer's rotation.

The DIM-BRIGHT dimmer knob adjusts the brightness or the reticle images. The ALIGN-FRICT is a two-position test switch. This switch permits either an image alinement check or a gyro pivot friction test when the selector switch is in the TEST position.

The last switch on the control box is the five-position selector switch. This control turns the equipment on or off, selects the various types of operation, and provides for testing. Each switch position is detent secured, and a test

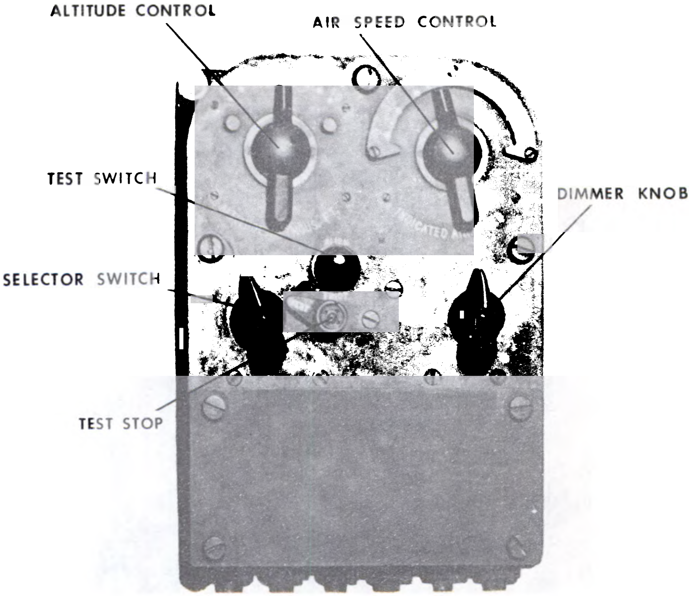


Figure 7–6.—Controls of the control box.

stop prevents accidental setting of the selector in the TEST position.

The selector switch, as shown in figure 7–6, performs the following functions:

1. Connects the windage and gravity circuit into the ballistic computer network in the FIXED & GYRO and GYRO positions.
2. Connects the range coils to the time-of-flight circuit in FIXED & GYRO and GYRO positions, and in TEST position when the test switch is closed in ALIGN position.
3. Connects the fixed lamp to the regulated power supply in FIXED, FIXED & GYRO, and TEST positions; and connects the gyro lamp to the regulated power supply in FIXED & GYRO, GYRO, and TEST positions.
4. Connects the servomechanism to the unregulated power supply in FIXED & GYRO, GYRO, and TEST positions.

5. Connects the voltage regulator to the unregulated power supply in all positions except OFF.

Sight unit controls.—There are three controls on the sight unit as shown in figure 7–7. The span handle, in conjunction with the span scale, establishes a basic diameter of the ranging circle when it is set at the known (or estimated) value for the wingspan of a sighted target aircraft. This is essentially stadiametric ranging as explained in chapter 3.

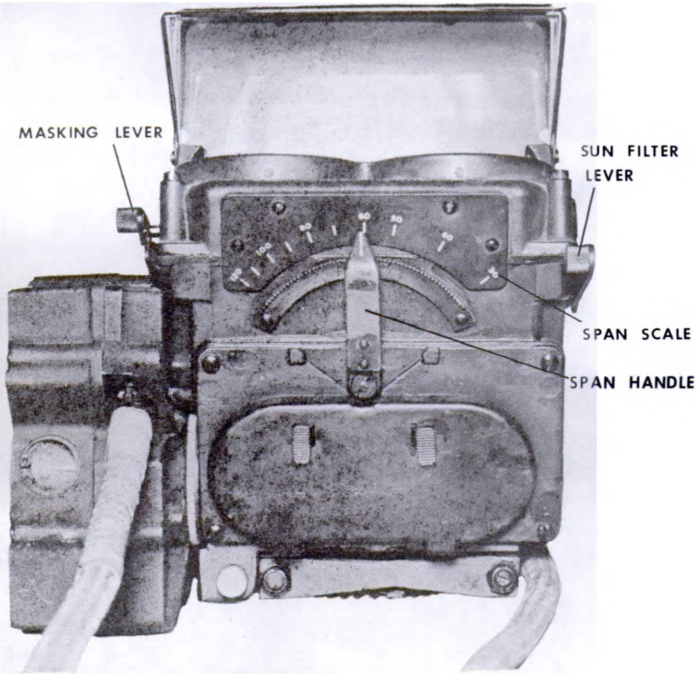


Figure 7–7.—Controls of sight unit.

The sunfilter lever raises a sunfilter into the field of vision to increase the contrast of the reticle images against a bright background. Raising this lever brings the sunfilter into the field of vision.

A masking lever is used to blank out the ring of the fixed reticle image if the ring is not desired. Depressing this lever blanks out the ring.

RANGE CONTROL.—Rotation of the input shaft on the range control operates a ranging servomechanism that varies the diameter of the gyro reticle image and sets target range into the computing mechanism. Rotation of this shaft is accomplished by means of a foot pedal and linkage. When the pedal is fully raised, the diamonds are as close to the center pip as possible (maximum range); when the pedal is fully depressed, the diamonds are as far from the center pip as possible (minimum range). When the pedal is fully raised, the gyro is caged so that the turret may be slewed without tumbling the gyro. When the pedal is depressed slightly to start ranging, the gyro is uncaged and a gun recorder camera can be placed in operation automatically to record tracking and firing results. The ranging mechanism is operative when the selector switch is on FIXED & GYRO, GYRO, and TEST positions.

Maintenance

Because of the similarities between the Mk 18 and AFCS Mk 6, the maintenance of the two equipments will be closely related. As an AQ3, besides being required to operate, perform operational tests, and make external adjustments, you are responsible for isolating casualties to major components. To perform these duties efficiently, it is recommended that a reliable inspection check be followed in determining the performance of the equipment.

Such a preflight or maintenance check will be found in the BuAer Publication NA 11–70 GAD–503. The preflight check given under the maintenance section of AFCS Mk 6 in chapter 5 of this course will also serve as the basis for developing such a check. Of course, the check for the Mk 6 will not completely suffice for the Mk 18 gunsight.

The line maintenance for this gunsight consists of the following checks, adjustments, and repairs to be performed by qualified maintenance personnel. As an AQ3, you will perform some of these by yourself, while on others you may assist more experienced technicians. The extent of your maintenance activity will depend upon your particular organization and your ability and experience.

1. Preflight checks.
2. Alinement and boresighting.
3. Gyro friction tests.
4. Zero centering (synchronization of the azimuth and elevation units with the turrets).
5. Checks for trouble isolation, including circuit tests and test of isolated control units.
6. Check and adjustment of the ranging servomechanism.
7. Replacement of line maintenance parts.
8. Checking and adjusting the voltage regulator.

It is pertinent to note that maintenance personnel are not authorized to make any repairs on the internal parts of the sight unit or the resistance networks of the control units, except as outlined. Work beyond the scope of maintenance personnel should be sent to an overhaul shop.

ALL-WEATHER DEFENSIVE CONTROL SYSTEM

The second basic type of aircraft turret control is the radar all-weather defensive control system. As representative of this type of equipment, let us consider a tail turret control system, for example, the Tail Turret System Aero 21B. The purpose of such a turret control system is to search for targets to the rear of the aircraft and to track any target selected by the gunner. The search pattern may be controlled automatically by the equipment, or a particular area may be searched manually. In track operation, ballistic and relative motion factors are automatically calculated and turret guns are continuously positioned. This system is essentially a director-type bomber defense system which will hit a maneuvering target at any time after coming within a specified range.

Principles of Operation

The three main elements of this turret control system are the tracking device (radar), the computing device (computer), and the gunpointing device (turret). The radar portion of the system transmits RF pulses which are reflected from the target within the radar beam. The radar beam may be positioned anywhere within the total coverage area. Received echoes presented on the scopes define the target position in terms of relative azimuth, elevation, and range. Targets within a given section of the coverage area can be observed by the gunner when the equipment is placed in automatic search operation. In manual search operation the gunner can select any given target for concentrated observation. From either of these modes of operation a single target can be selected for automatic tracking.

Tracking is accomplished by successively shifting the beam about the scanner centerline through the pattern shown in figure 7–8. This is called SEQUENTIAL LOBING of the radar beam. By comparing received signals from left and right lobes, which represent different aspects of the target, an

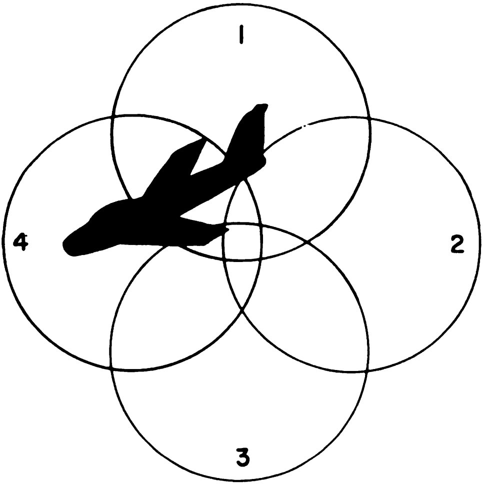


Figure 7–8.—Radar beam lobing pattern.

error voltage is developed for training the scanner on target in azimuth. Similarly, echoes from the up and down lobes are compared and used to keep the scanner on target in elevation.

The computer receives continuous data concerning target range, position, and angular positional change; then it solves the fire control problem. The computer output is a gun order signal to the turret, which, when applied to the turret servos (control system), keeps the turret at the proper lead angle to effect hits on a maneuvering target within a specified range.

Block Diagram

A simplified block diagram, giving the information flow, of the turret system in track operation is shown in figure 7–9. In track operation both scanner and turret are automatically positioned by the equipment. During automatic search operation, the scanner is controlled by the equipment and the turret by the gunner. During manual search, both the scanner and the turret are controlled by the gunner.

Tracking is initiated by transmitting a radar pulse into space through the scanner. At the scanner, by use of a rotating shutter with three windows and by feeding the RF energy into four waveguides, beam lobing is accomplished. (One waveguide at a time is blocked by the shutter.) The pulse signal, reflected from the target back to the scanner, is then returned to the SYSTEM CENTRAL unit, where the error signals in azimuth and elevation are generated.

These error signals are used for scanner position control. As shown in figure 7–9, they are fed from the radar to the correlator where they are amplified and fed to the scanner servomechanism. Thus, the received signals are used as the basis for positioning the scanner. An examination of the lobing pattern in figure 7–8 shows that the echo returned from lobe 4 is stronger than from lobe 2, and the echo from lobe 1 is stronger than that from lobe 3. This situation would result in a signal which would cause the scanner to move to the left and up.

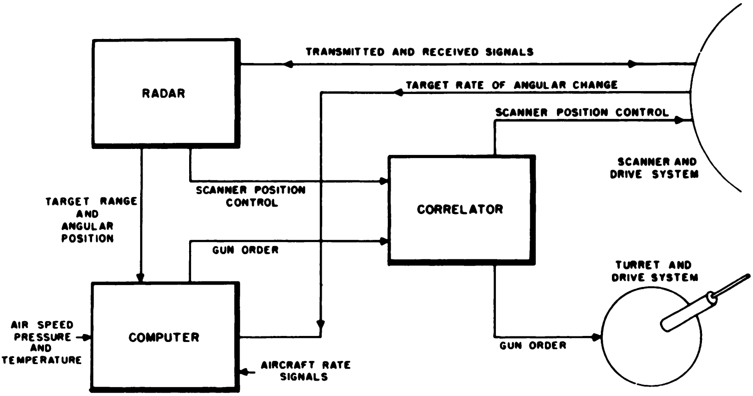


Figure 7–9.—Simplified block diagram of turret system in track operation.

Target tracking is performed in three dimensions: Azimuth angle, elevation angle, and range. Signals proportional to all three variables are fed to the computer from the radar. The computer then calculates the exact instantaneous lead information based upon these signals and other data supplied by the system. The result is that the system automatically establishes and maintains the proper total lead angle.

Computer operation, then, is based upon the various signals received from the other components. Range tracking circuits in the system provide a voltage proportional to the range of the target. Rate gyros and information relaying devices on the scanner provide the information as to the position of the line of sight to the target and the rate at which this position is changing. (See fig. 7–9.) A separate rate gyro unit provides climb and turn data (aircraft rate signals) to the computer.

With all this information as input, the computer solves the fire control problem by operation on these factors and the ballistic factors, such as airspeed, pressure, and temperature. It delivers a gun order signal to the turret control circuits in the correlator, which positions the turret at the proper lead angle to effect hits on the moving target.

The function of the computer may be summarized by stating that it is continually engaged in providing two major predictions: (1) Future position of the target, and (2) projectile trajectory necessary for arrival at this future position simultaneously with the target. The kinematic section of the computer provides future target position, while the ballistics section furnishes the trajectory prediction. These two solutions are combined in the computer, giving the total lead angle necessary for hitting the target any time after it comes within firing range. A simplified representation of the fire control problem solved by this equipment is shown in figure 7–10.

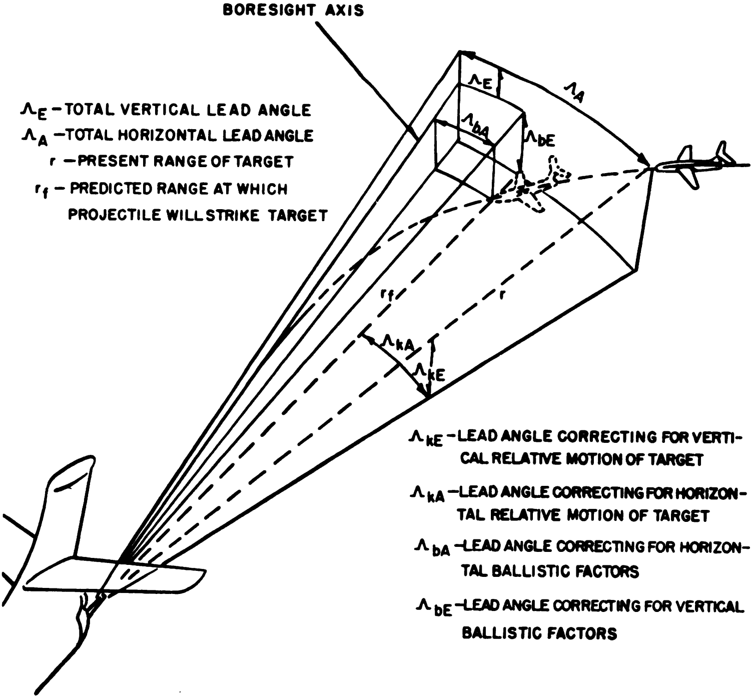

BORESIGHT AXIS
Λ_E – TOTAL VERTICAL LEAD ANGLE
Λ_A – TOTAL HORIZONTAL LEAD ANGLE
r – PRESENT RANGE OF TARGET
r_f – PREDICTED RANGE AT WHICH PROJECTILE WILL STRIKE TARGET
Λ_E
Λ_A
Λ_{bA}
Λ_{bE}
r_f
r
Λ_{kA}
Λ_{kE}
Λ_{kE} – LEAD ANGLE CORRECTING FOR VERTICAL RELATIVE MOTION OF TARGET
Λ_{kA} – LEAD ANGLE CORRECTING FOR HORIZONTAL RELATIVE MOTION OF TARGET
Λ_{bA} – LEAD ANGLE CORRECTING FOR HORIZONTAL BALLISTIC FACTORS
Λ_{bE} – LEAD ANGLE CORRECTING FOR VERTICAL BALLISTIC FACTORS

Figure 7–10.—Geometry of the fire control problem.

Major Components and Functional Operation

The major components of this type of turret control system are: (1) Gunner's console, (2) gunner's control handle, (3) system central, (4) computer, (5) turret and tailcone, (6) scanner, and (7) correlator. Although there are other components and the part they play in the overall operation of the equipment.

GUNNER'S CONSOLE.—The gunner's console is the primary control and indicating component of the system. It contains all the operating controls except those in the gunner's control handle. Two large scope presentations, the B scope (azimuth vs. range) and the C scope (azimuth vs. elevation), provide clear visual target information during all stages of search operation. It should be noted that the B presentation becomes an A presentation during track.

The console also has a viewing hood which may be fastened over the two indicator scopes. The purpose of the hood is to aid the gunner's observation by eliminating reflections of extraneous light. The control knobs are all conveniently grouped and specially designed for touch-system use when the gunner's vision is occupied with the scope presentations.

GUNNER'S CONTROL HANDLE.—The gunner's control handle, which is mounted in a gimbal arrangement, affords control over the turret and scanner position, and contains the controls for locking-on the target and firing the guns. Thus, it controls target acquisition and gunfire, and positions the radar scanner in manual search operation.

Located within convenient reach of the gunner's console, this handle grip is mounted vertically for right-hand operation moving forward and backward or side to side as desired for positioning in elevation and azimuth, respectively.

Mounted on this control are four switches, ACCEPT, REJECT, ACTION, and TRIGGER, which are used by the gunner to control the system. By depressing the action switch in manual or automatic search operation, the turret follows the control handle position as does an indicating circle (called a cursor) on the face of the C scope. This action switch also serves as a safety device, since it must be depressed by normal pressure of the hand in gripping the control handle, before gunfiring can commence.

Lock-on occurs when the gunner depresses the accept switch, having previously selected a target during search and followed it on the C scope. Following the target is accomplished by manual operation of the control handle until the target "blip" is centered in the circular cursor on the face of the C scope. This action causes the scanner to take the position set up by the control handle; also an electronic range measuring signal (range gate) searches for the target echo. Lock-on takes place when the target echo is located electronically by this range gate. After lock-on, range only is shown on the console B scope.

SYSTEM CENTRAL.—The system central houses the radar system circuitry, including synchronizer, postamplifier, range tracker, sea clutter, and power supplies. Grouped with the system central are the system junction box and modulator.

The synchronizer receives a timing shutter pulse from the scanner and supplies to the modulator the pulse which initiates the radar cycle. The modulator delivers a high voltage pulse to energize the final stage (magetron) after receiving the low level pulse from the synchronizer. The postamplifier strengthens the received signals and converts them to video signals for presentation on the scopes for use in the automatic tracking circuits. The synchronizer also compares the received signals from opposite scanner lobes, deriving a voltage from them to keep the scanner trained on the target during tracking.

The range tracker supplies information to the computer concerning the range of the target. The sea-clutter circuits are used to control the position of a tracking signal (called the tracking gate), under certain conditions of noise or interference, as an aid in locking-on a target. The system junction box serves as the central distribution point for the control and operating voltages of the system. Relays provide proper operating sequence by performing switching operations necessary to the various modes of operation.

One of the design features of this equipment is the use of book-type, pullout construction of chassis and components in the system central. Plug-in units and built-in test points are also provided to simplify replacement of units and to reduce troubleshooting time. Proper use of these features should result in easier testing and maintenance.

COMPUTER.—The purpose of the computer is to deliver gun positioning information to the turret components so as to enable successful firing at a moving target. In order to produce this information, the computer receives continuously varying data when a target has been locked-on, such as radar range, true airspeed, air density, target angular velocity and position, and gun position. After receiving this information, the computer solves the firing problem as it changes at each instant. This continuous process of electromechanical calculation provides gun positioning information to the turret through the correlator and turret drive system. When the target comes within firing range, the firing signal is given by illumination of a lamp on the console.

TURRET AND TAILCONE.—The turret and tailcone assembly (fig. 7–11) includes turret, tailcone, hydraulic transmission for driving the turret, radar scanner, scanner junction box, radome, and guns and gun accessories.

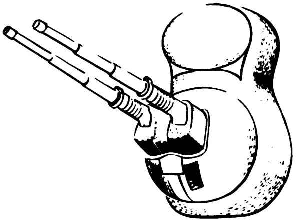


Figure 7–11.—Turret and tailcone.

The turret ball is suspended vertically within the tailcone by means of upper and lower trunnion assemblies—pivots on which the turret turns. Approximately one-half of the ball protrudes from the structure. A dual hydraulic pump, driven by a single electric motor, provides hydraulic power for driving the turret in azimuth and elevation.

The output of one of the pumps is connected to the azimuth drive hydraulic motor, which is coupled with the azimuth drive gear train. The other output is similarly connected to the elevation hydraulic motor and elevation gear train. A limit mechanism prevents motion in excess of a prescribed maximum.

In this turret control, a pneumatic system is used for gun charging, and pressurizing the RF head, the modulator, and the waveguide. This pneumatic system consists of a three stage air compressor, a pressure tank, associated relief and regulator valves, and a dehydrator. Thus, the experienced AQ will have to be familiar with pneumatic and hydraulic systems to completely maintain this equipment.

Scanner.—The scanner consists of a reflector and feed horns with associated drive and indication mechanisms, all mounted on a common base. The scanner is situated directly above the turret in the tail section. (See fig. 7–11.) Energy from the four feed horns is concentrated by a paraboloidal aluminum reflector into the required narrow beam. Each of these individual feed horns is blocked in succession by a lobe switching assembly in the scanner to produce a shifting of the pattern for tracking purposes.

Separate drive motors and gear trains position the reflector in azimuth and elevation in accordance with control voltages from the correlator. Position potentiometers on the two gimbals (azimuth and elevation) provide scanner azimuth and elevation information to the scopes on the gunner's console. Also, two rate gyros on the scanner measure the rates of changes of the motion of the reflector in azimuth and elevation, and thus, indirectly, the angular movement of the target being tracked.

Correlator.—The correlator acts as a clearing house for the processing of radar, scanner position, and turret position signals during the various modes of operation, by means of servo amplifiers. A servo amplifier is part of a servomechanism system which is defined in chapter 17 of *Basic Electricity*, NavPers 10086, as a special type of automatic control system. The correlator, then, contains both turret and scanner servo amplifiers and a circuit called the search signal generator.

Depending upon the mode of operation, either the search signal generator, the synchronizer, or the gunner's control handle furnishes the input for the SCANNER servo amplifier. The search signal generator is a programming device that drives the scanner in the automatic search pattern. It is disconnected when the system is in the manual search mode of operation. The synchronizer is used to supply the input during tracking, while the control handle is used during manual operation. The input to the other control system, the TURRET servo amplifier, is derived from the gunner's control handle during target acquisition, and from the scanner via the computer during automatic tracking.

Modes of Operation

There are five modes of operation of this equipment; namely, standby, automatic search, manual search, acquisition, and track. By proper use of the controls, any of these modes may be selected by the gunner. A possible sixth mode of operation would be the firing of the guns which is the culmination of the tracking.

STANDBY.—This mode is selected by turning the 400-cycle overload switch and master armament switch ON, but the radar switch OFF. In this condition, the turret system has all tube filaments, computer, and low voltage plate supply voltages turned on and is ready for full operation. In addition, power is applied to gyro wheels, blower motors, and the scanner lobing motor. The radar does NOT operate.

AUTOMATIC SEARCH.—In the automatic search mode, the radar is operating and the scanner is controlled by the search signal generator. The turret is controlled by the gunner's control handle.

In this mode, the automatic pattern traced by the radar beam in space is shown in figure 7–12. While the angular displacement of the pattern remains constant in both azimuth and elevation, the location in elevation is controllable. This location in elevation of the scan pattern may be any one of five selectable sectors. In general, the elevation sector depends on aircraft altitude and on tactical considerations. The

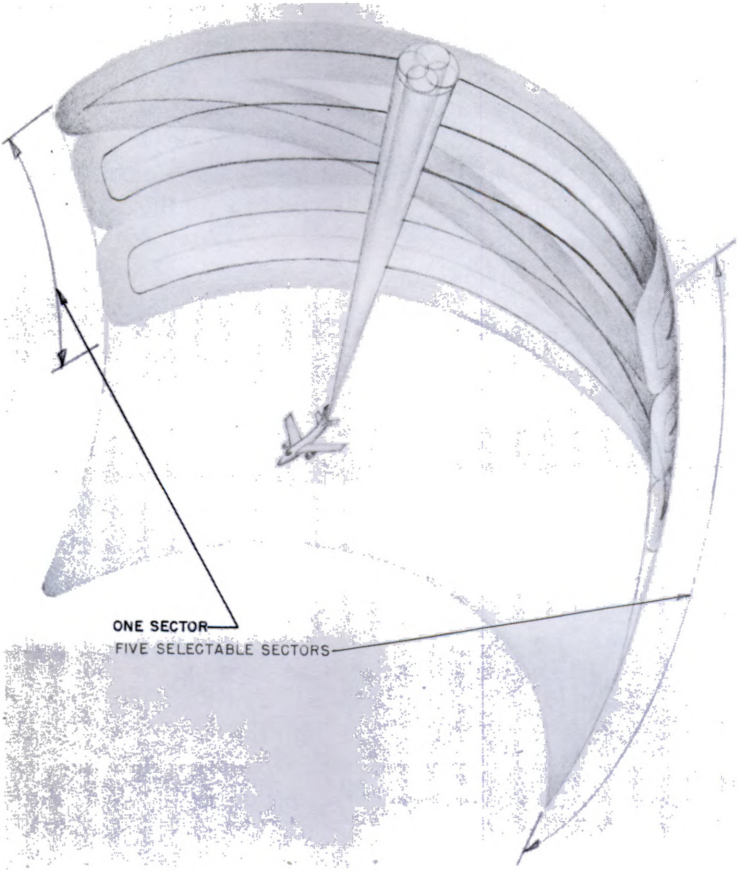


Figure 7–12.—Radar automatic search pattern.

operator can determine the elevation sector by the control setting on the console. He can also observe which sector has been selected by the display on the right-hand C scope.

During automatic search, when the action switch is depressed the turret and cursor follow the position of the gunner's control handle. The scanner will continue to operate in the automatic search pattern.

In search operation and prior to lock-on, the presentation on the left scope is type B. (See fig. 7–12.) The dots indicate the azimuth and range of the targets. The relative azimuth of a target is estimated from the horizontal azimuth scale, and the target is to port or starboard according to where it appears in respect to the vertical centerline of either scope. The target range is determined from range marks etched on the window in front of the scope. IFF (identification, friend or foe) can also be presented on the B scope during search.

The C scope indicates relative azimuth of the target measured along the horizontal scale and elevation along the vertical scale. A target appearing above or below the horizontal reference line represents elevation relative to the centerline of the aircraft. Thus, the target in figure 7–13 is to the right and below the centerline of the aircraft.

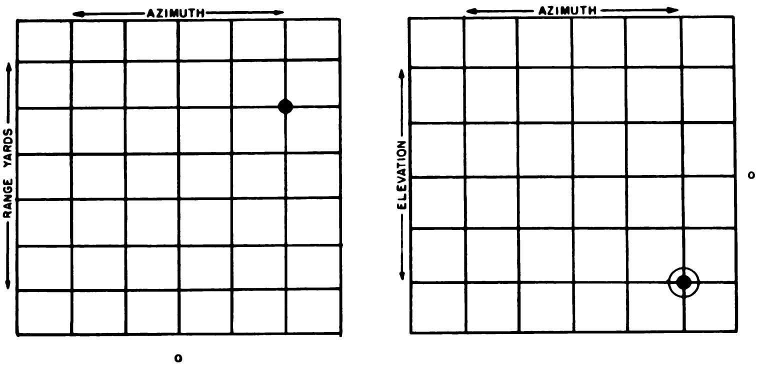


Figure 7–13.—Scope presentation, automatic search, action switch, depressed.

A circular cursor appears on the C scope when the gunner depresses the action switch on the gunner's control handle. The position of the cursor is determined by the placement of the gunner's control handle. When the radar is in automatic search mode, the cursor indicates the azimuth and elevation bearing of the turret.

Manual search.—When the system is in manual search operation, the scanner follows the movement of the gunner's control handle. The operator can position the scanner anywhere within the total coverage area. When the action switch is depressed, the turret and cursor also follow the position of the gunner's control handle.

ACQUISITION.—This mode is the selection of a specific target during search. Selection is accomplished by depressing the action switch and then placing the cursor around the desired target on the C scope. To lock-on the target, the operator depresses the "accept" switch which is also on the gunner's control handle.

TRACK.—Once the system has locked-on a target, it goes to track operation where the scanner and the turret do not respond to the movement of the gunner's control handle. The action switch must always be depressed for track operation. The scanner automatically follows the angular movement of the target, and the turret position is governed by that of the SCANNER until the target is within range. When the target is within range, the computer ADDS the computed lead angle to the scanner position to obtain the turret's position. The turret position, then, is equal to the sum of the scanner position and the total lead angle. The signal that controls this turret position is called the GUN ORDER SIGNAL. Evidence that the turret is following the gun order signal from the computer is given by an indicator lamp.

In track operation, the received signals are used as the basis for positioning the scanner. As previously mentioned, the radiated beam is shifted about its centerline to obtain samples of the target in each of the four lobes in rapid succession. Positioning of the scanner is accomplished by comparing the signal strength of opposite lobes.

When the system has been locked-on a selected target, the presentations are changed on both scopes on the gunner's console. The B scope is changed to a type A presentation, indicating range only. (See fig. 7–14.) Horizontal information from the scanner is disconnected, and the vertical range trace remains centered on the scope regardless of scanner position.

The target appears on the A scope to the right of the vertical sweep. An electronic signal, called the tracking gate, indicates the range of the target at which the system is locked-on. This signal appears to the left of the center vertical trace, centered around the tracked target.

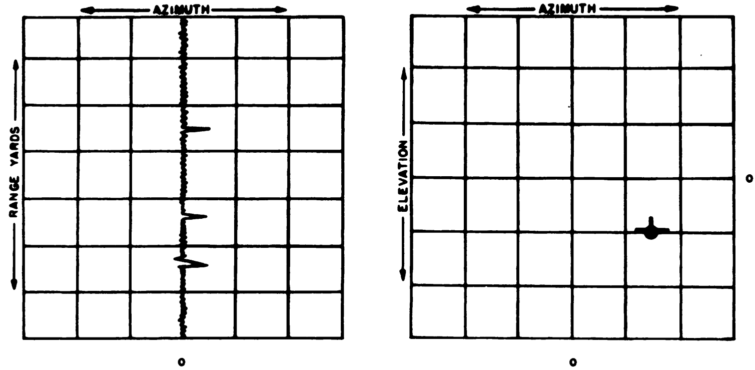


Figure 7–14.—Scope presentation after lock-on.

The dot on the C scope, after lock-on, indicates the azimuth and elevation angle of the scanner. After the predicated range of the target being tracked decreases to a predetermined value, the C scope presents range rate information. At this range, a fixed, horizontal reference line appears through the dot on the C scope, and the relative range rate is given by a vertical line. (See fig. 7–14.) A closing target is represented by a deflection upward from the horizontal reference line, and an opening target as a downward deflection. The length of the vertical line is proportional to the rate at which the target's range is increasing or decreasing.

When the system is locked-on a target, depressing the "reject" button on the gunner's control handle terminates automatic tracking. The system returns to the type of search corresponding to the position of the console controls. Releasing pressure on the action switch returns the turret to its stowed position and removes the cursor from the C scope.

Operating Controls

All the operating controls for this type of turret control system are located on either the gunner's console or the gunner's handle. All the variable controls for adjusting the console presentation are fitted with knobs of distinctive shapes so as to be recognizable to the touch. The gunner's console also contains the two cathode-ray-tube indicators which furnish range, azimuth, and elevation information. The gunner's console is shown in figure 7–15 and the gunner's control handle in figure 7–16. The number in parentheses after each control in the following description refers to the numbers on figures 7–15 and 7–16.

GUNNER'S CONSOLE.— The LOCK IN (2) is a green lamp which glows when the tail turret is locked-on a target. The SYNC (3) is an amber lamp which glows when the turret is following the input signals properly and when the turret is stowed. The IN RANGE (4) is a red lamp which lights when the future range of the target decreases to a predetermined value.

The left scope (1) gives type B presentation in search operation with the range indicated vertically and azimuth horizontally. In track operation the left scope gives type A presentation displaying range vertically. The right scope (5) presents elevation vertically and azimuth horizontally.

The port (6) and starboard (27) gunfiring indicators flash each time the port and starboard guns, respectively, fire. The REC TUNE (7) is both a knob switch and potentiometer. Clockwise rotation cuts out the automatic-frequency-control circuits and permits manual control of the receiver frequency. Normally this control is in the AFC position. Both INT controls (8) and (25) are triangular in shape and both are used to control the intensity of a scope. The one on the right side controls the C scope, while the one on the left side controls the A–B scope.

The FOCUS controls (9) and (24) are square knobs. The right side control is used to control the definition of the C scope while the left one controls the A–B scope. The COMPUTER (10) is a two-position toggle switch which is normally in the IN position. In the BYPASSED position, the computer lead angle is removed from the gun order signal, so that the turret points at the target's true position. The PANEL LIGHTS (11) is an elliptical knob used to adjust the illumination of the control panel lights.

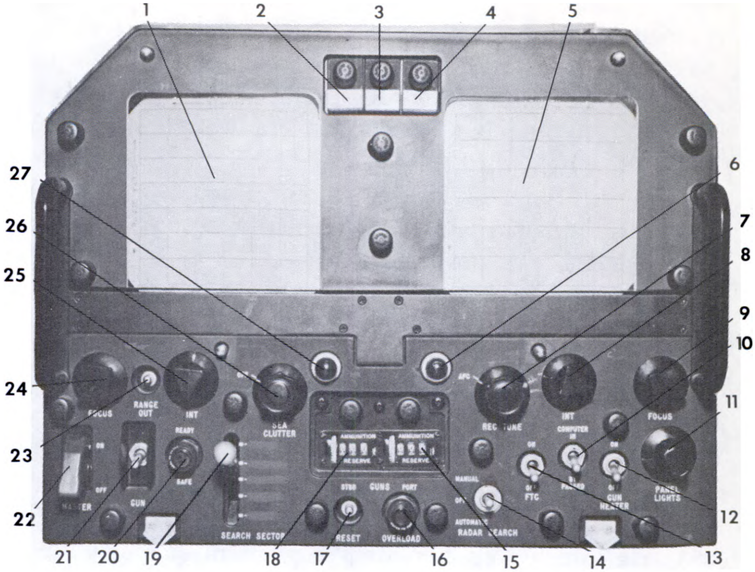


Figure 7–15.—Gunner's console.

The GUN HEATER (12) is a two-position toggle switch which controls power to the gun heaters. The FTC (13) is also a two-position toggle switch. In the ON position it improves definition of closely-spaced targets, and is also useful in the presence of jamming. This switch is normally in the OFF position. The RADAR SEARCH (14) is a three-position toggle switch. In the OFF position, the control system is in standby. In MANUAL or AUTOMATIC position, it selects the type of search operation and turns on the tail turret system.

The PORT (15) and STARBOARD (18) GUN AMMUNITION RESERVE counter dials indicate the number of rounds remaining in the respective guns. The MOD OVERLOAD (16) lamp glows when the modulator overload, the overvoltage relay or the power supply protective circuit has operated. For minor or momentary overloads, the modulator overload relay automatically recycles causing the lamp to flash briefly. The MOD RESET (17) is a pushbutton which permits manual resetting of modulator overload and overvoltage relays.

The SEARCH SECTOR (19) selects one of five elevation sectors to be scanned by the radar. The SWITCH TO READY (20) is a red lamp used to indicate the position of the GUN switch when the action switch is depressed. If the GUN switch is on SAFE, this lamp glows. GUN (21) is a two-position switch which is normally in the SAFE position. In READY position, it permits firing of guns. The MASTER switch (22) is also a two-position toggle switch with a protective guard. It is the primary power switch for the system, and the system becomes ready to operate approximately 4 minutes after this switch is thrown to ON initially.

The RANGE OUT (23) pushbutton permits selection and lock-on of targets, other than those nearest in range, at a given azimuth and elevation. The SEA CLUTTER (26) is a knurled knob switch and potentiometer which is normally in the OFF position. It enables the gunner to obtain clear presentation of the target when there is clutter, interference from mountains, or jamming of the desired target.

GUNNER'S CONTROL HANDLE.—The gunner's control handle (fig. 7–16) positions the turret and scanner as well as the C-scope cursor, depending on the mode of operation. In manual search with the action switch OPEN, it positions the scanner only. In manual search with the action switch CLOSED, it positions scanner, turret, and cursor. When the equipment is in automatic search operation and the action switch is OPEN, the handle has no effect, but when the action switch is CLOSED it positions both the turret and cursor. In track operation, the handle loses control of the system when lock-on occurs.

The A (accept target) pushbutton located on top left of the handle is used to acquire targets. Depressing this switch causes the tail turret system to lock-on a target. The pushbutton should be held down until the LOCK IN lamp glows. The R (reject target) pushbutton located on top

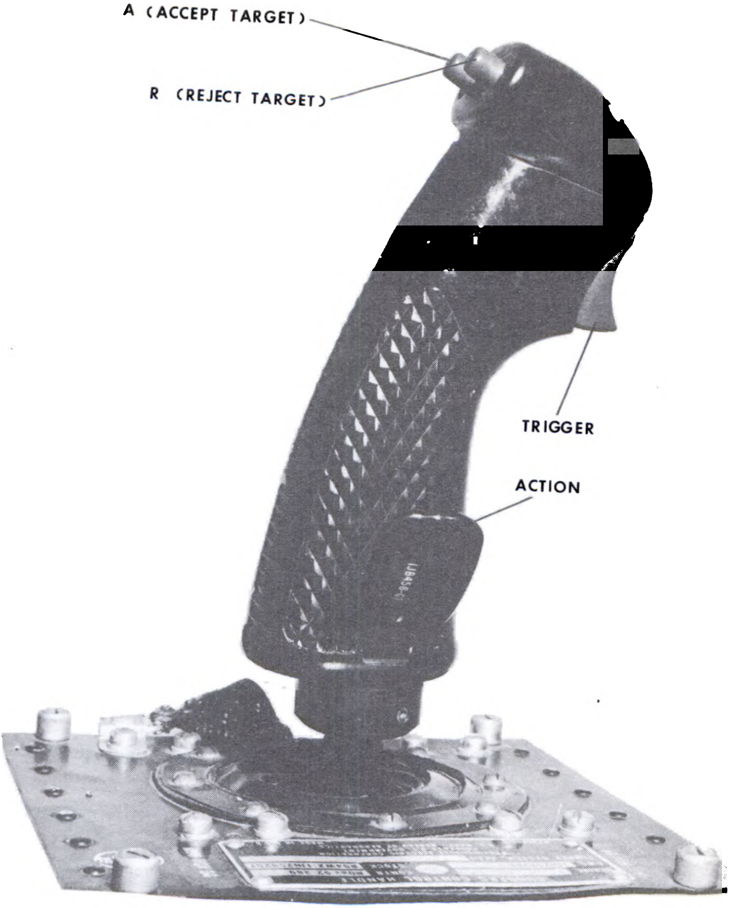


Figure 7–16.—Gunner's control handle.

right of the handle is used to terminate automatic tracking. When this pushbutton is depressed, the system returns to the type of search selected by the RADAR SEARCH switch on the console.

The trigger controls the firing of the guns. It has no effect unless the GUN switch on the gunner's console is in READY position, and the action switch is closed. The action switch is a spring-loaded switch at the base of the handle. When depressed, it places the cursor on the C scope and energizes the turret power drive. The turret will follow the control handle position when this switch is depressed in manual or automatic search. Releasing this switch stows the turret, and removes the cursor from the C-scope. The return of the turret to the stowed position de-energizes the power drive.

Maintenance

As you can see, this type of all-weather defensive control system is a complicated, automatic system. As an AQ3, the degree of maintenance you will be called upon to perform on this type of equipment will vary with the particular organization to which you are assigned and to the needs of the service. You should be able to energize and secure the equipment, set the operating controls, make operator's adjustments, and read and interpret the dials. Also you should be capable of interpreting the cathode-ray-tube presentations, plus performing operational tests.

In troubleshooting, you will be required to locate and identify the major components and subassemblies. Isolating a casualty to the major component will be the first step in repairing a malfunction. To be able to do this, you will have to know the purpose and function of the blocks given in the block diagram. How the information flows from block to block will be a great asset in determining where the difficulty exists. The possibility also exists that you will be required to perform more complicated troubleshooting under the supervision of the chief or other higher rated men.

It cannot be overemphasized that proper adjustment and alinement is mandatory for effective operation of the equipment. Maintenance manuals which have been prepared on the specific equipments contain the information and procedures necessary for the adjustment, alinement, and maintenance of the system.

QUIZ

1. The Mk 18 Mod 6 computing gunsight establishes a lead angle for ___________ projectiles.
   a. .50-cal. only
   b. .50-cal. and 20-mm
   c. 20-mm only
   d. .30-cal. and .50-cal.
2. When using the Mk 18 Mod 6 gunsight, the proper lead angle will be established if the gunner tracks and frames his target smoothly and has manually set into the sight values for
   a. airspeed, altitude, and wingspan
   b. airspeed, altitude, and gravity
   c. groundspeed, altitude, and wingspan
   d. range, altitude, and gravity
3. The Mk 18 Mod 6 gunsight, in computing lead, automatically compensates for
   a. altitude, range, windage, and gravity
   b. relative target motion, time of flight, range, and gravity
   c. relative target motion, time of flight of the bullet, windage, and gravity
   d. range, altitude, airspeed, and gun position
4. In the Mk 18 Mod 6 computing gunsight, the range coil current is equivalent to the
   a. angular tracking rate
   b. bullet time of flight
   c. range and gravity
   d. altitude and airspeed
5. In the Mk 18 Mod 6 computing gunsight, as the gunner tracks the target, the gyro or computer image will
   a. lead the fixed image
   b. stay right with the fixed image
   c. indicate where the guns are pointing
   d. lag behind the fixed image and guns
6. Trail offsets in the Mk 18 gunsight are allowances for
   a. range and gravity
   b. windage and gravity
   c. gravity and airspeed
   d. airspeed and altitude

7. Effectively, current through the trail coils causes the magnetic field
    a. to increase in strength
    b. to decrease in strength
    c. to center
    d. center to shift

8. Two variable factors which affect gravity coil current are
    a. range and airspeed
    b. altitude and airspeed
    c. range and gun elevation
    d. altitude and gun elevation

9. When the Mk 18 Mod 6 gunsight is caged, there is
    a. excess current flow in the range coils
    b. less current flow in the range coils
    c. excess current flow in the trail coils
    d. no change in the current flow in the range or trail coils

10. When is the azimuth coil current reversed by the azimuth unit?
    a. 90° and 270° in azimuth
    b. 0° in azimuth
    c. 90° in azimuth
    d. 0° and 180° in azimuth

11. When is the current from the elevation unit to the elevation coils reversed?
    a. 270° in elevation
    b. 180° in elevation
    c. 90° in elevation
    d. 0° in elevation

12. The purpose of the voltage regulator in the Mk 18 Mod 6 gunsight is to provide a constant
    a. 28-volt d-c supply
    b. 24-volt d-c supply
    c. 23-volt d-c supply
    d. 22-volt d-c supply

13. In airborne all-weather defense systems, such as the tail turret control system, azimuth and elevation position information is obtained by
    a. rotating the scanner's reflector
    b. rotating the scanner's feed horn
    c. optical means
    d. a sequential lobing pattern

14. In the tail turret control system, range and azimuth information are presented to the gunner on a/an
    a. A scope
    b. B scope
    c. C scope
    d. PPI scope

15. In the tail turret control system, the computer output is used to
    a. position the scanner only
    b. position the scanner and turret
    c. position the turret only
    d. guide the defending aircraft on an evasive course

16. The dimensions used during target tracking in the tail turret control system are
    a. azimuth angle, elevation angle, and range
    b. azimuth angle and elevation angle
    c. azimuth and elevation lead angle
    d. azimuth lead angle, elevation lead angle, and future range

17. The primary control and indicating component of the tail turret control system is the
    a. computer
    b. system central
    c. gunner's control handle
    d. gunner's console

18. In the tail turret control system, the gunner controls the scanner manually with the
    a. search signal generator
    b. control handle
    c. search sector control
    d. computer outputs

19. With a target "in range" during "track" operation, the turret of a radar controlled aft firing defense system is positioned at the
    a. scanner position
    b. discretion of the gunner
    c. scanner's position plus total lead angle
    d. stowed position

20. In the tail turret control system, which of the following DOES NOT supply the input to the SCANNER servo amplifier?
    a. Computer
    b. Synchronizer
    c. Gunner's control handle
    d. Search signal generator

21. When switching to track operation, the A-scope operation utilizes a scope that was formerly a/an
    a. unused scope
    b. B-scope operation
    c. C-scope operation
    d. PPI-scope operation

22. In the tail turret control system, releasing the action switch causes the
    a. system to go to STANDBY
    b. system to lock-on a target
    c. scanner to stop searching
    d. turret to go to a stowed position

23. In the tail turret control system, the gunner's control handle is used to position the turret and scanner during
    a. standby
    b. automatic search operation
    c. manual search operation
    d. tracking operation

24. In the tail turret system, the SEARCH SECTOR selector switch allows 5 sections to be selected, each having
    a. 60° in azimuth
    b. 15° in azimuth and 45° in elevation
    c. 45° in azimuth and 15° in elevation
    d. 60° in elevation

25. Since the operator of the tail turret control system is positioned forward in the aircraft, how will he know when all of the ammunition has been fired?
    a. The radar will automatically secure itself
    b. The turret will automatically stow itself
    c. The radar will secure and the turret stow automatically
    d. The ammunition counter dials will read zero

CHAPTER 8

BOMB DIRECTORS

TYPES AND DEVELOPMENT

The development and methods of bombing was discussed in detail in chapter 3, "The Fire Control Problem," of this course. You will recall, that after pointing out the factors that determine the type of bombing to be used, the bombing methods were described. The methods were divided into the following categories: Level bombing, both high and low; dive and glide bombing; toss bombing; and loft bombing. The purpose of the bomb aiming equipment was also given in this previous chapter; for emphasis, let us restate this purpose. Accordingly, all bombsights and bomb directors furnish information which will assure a hit if the pilot will put his plane at the point indicated, and if the missile is dropped in accordance with the predetermined ballistic formulas. The primary purpose of all bombing tactics is to direct the maximum effective amount of firepower against a designated target.

If the principles presented under the bombing section of chapter 3 are now hazy to you, it is strongly recommended that you restudy that section. We propose now to briefly review, for emphasis, the bombing methods and then study the means by which the bomb directors and sights solve the bombing problem.

Level Bombing

The level or horizontal bombing problem is customarily presented first to introduce the bombing problem in general. The study of the action of a bomb in air should be started with a familiar situation. Such a situation is the bomb's action when dropped in a vacuum. The laws of physics give us formulas for the speed of a falling body. These formulas are expressed in terms of the attraction of gravity and the amount of time or distance through which it acts. The acceleration of a falling body is known as the acceleration of gravity (g).

VACUUM TRAJECTORY.—Due to the fact that a bomb is always dropped from a moving airplane, the bomb in a vacuum would retain, during its time of fall, any horizontal motion imparted to it by the plane. This motion would remain constant in magnitude and direction. If the aircraft did not alter its course or speed, the bomb would remain vertically below the plane as it fell and the plane would be directly over the point of impact when the bomb hit. The path that the bomb would follow when dropped from a moving plane is called the vacuum trajectory. This is shown in figure 8–1.

ACTUAL TRAJECTORY.—But bombs are not dropped in a vacuum. Under actual conditions, air resistance becomes a factor at the instant a bomb is released. Air resistance retards the forward motion of the bomb and opposes gravitational attraction to keep the bomb in the air longer. The exact effect of air resistance on a bomb depends upon the size and shape of the bomb as well as the release conditions. This effect of air resistance on a bomb is expressed as the ballistic coefficient of the bomb.

Wind also affects a bomb's trajectory along the line of flight and at right angles to it. A tailwind or a headwind does not affect trail but affects groundspeed, and this in turn affects whole range as shown in figure 8–1. Trail, which is the horizontal distance between the points of impact of the actual trajectory and a vacuum trajectory, is dependent upon: (1) Airspeed at the time of release, (2) altitude, and (3) the ballistic coefficient.

Since trail is unchanged by wind, the real effect of wind is upon actual range. Actual range, as shown in figure 8–1, is the horizontal distance the bomb travels between release and impact. Thus, the headwind will reduce actual range

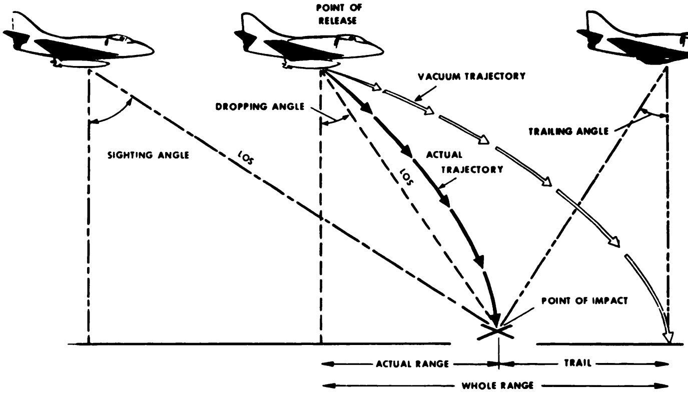


Figure 8–1.—Basic phases of the horizontal bombing problem.

and thereby move the proper point of release closer to the target. A tailwind has the reverse effect and moves the point of release further from the target.

Drift problem.—A cross wind causes the aircraft to drift off its intended course and is compensated for by the pilot. He does this by changing the heading of the plane thereby causing it to "crab" as shown in figure 8–2. Cross wind also imparts a drift to the bomb which result in an impact behind the aircraft and downwind from the true course. The ground distance from the point of impact to the true course is known

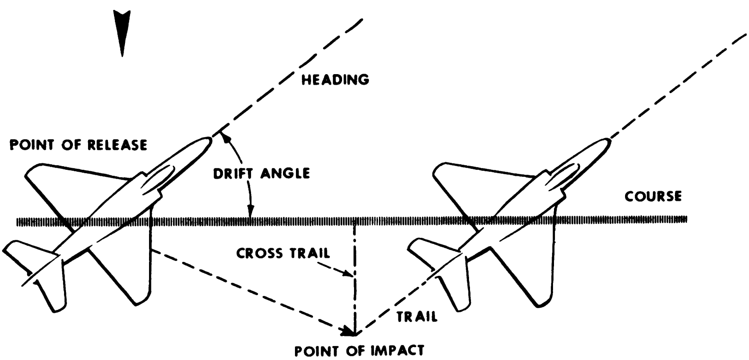


Figure 8–2.—Effects of cross wind on bomb trajectory.

as CROSS TRAIL. (See fig. 8–2.) This error can be compensated for in the bombsight.

SOLUTION OF PROBLEM.—Usually the solution of the horizontal bombing problem is done by the bombsight in terms of angles rather than distances (called the range angle solution method). For this reason all values with the exception of altitude are put into the bombsight as angles in the form of mils. The bombing mil is the angle subtended by an arc whose length is one-thousandth of the range. A more complete discussion of the mil is found in chapter 2 of this course.

Target motion is not a serious problem in this type of solution. Target motion is resolved into components along and at right angles to the plane's heading. The portion along the plane's heading gives the same effect as a headwind or a tailwind. The components at right angles is considered as a cross wind and absorbed in the solution of the drift angle. Hence, the effect of target motion is merely to change the values of aircraft and wind velocity and then regard the target as motionless.

It should be emphasized that the previous discussion applies only to horizontal bombing which serves as a basic model for all types of bombing problems. The famous Norden bombsight, the Mk 15, visually solved the bombing problem as presented here. During and since World War II radar sights have been extensively employed. They present one great advantage; namely, that an attack is possible without visual sight of the target. An offset aiming feature in the radar sight makes possible the hitting of a poorly defined radar target by using some other well-defined object as a reference point.

In horizontal bombing a compromise must be reached between low and high altitude of attack. Generally, low altitude provides maximum accuracy but gives minimum protection against interception and antiaircraft fire. High altitude gives better protection but less accuracy, and the target must be large enough to be vulnerable over a considerable area. In the solution of the low level bombing problem, the

ANGULAR RATE method of solution is used in preference to the range angle method.

Horizontal bombing does not place undue stresses on the aircraft structure and therefore the plane is able to carry a comparatively large payload.

Dive and Glide Bombing

In dive bombing the plane descends toward the target at an angle of 60 degrees or more, thus imparting considerable vertical velocity to the bomb at the moment of release. In a steep dive, with the bomb released at 2,000 to 6,000 feet, time of flight is short and air resistance, wind, and target motion are small. The problem of obtaining accuracy is simplified and a good percentage of hits can be obtained by the use of a simple lead-computing sight. A fixed sight and rule of thumb methods may also be used.

Advantages inherent in dive bombing are that impact velocity is increased by the plane's velocity, a high degree of accuracy can be obtained, essential bombing equipment is relatively simple, the bombing run is comparatively short, and there is desirable psychological effect upon exposed enemy personnel. On the other hand, a high dive angle causes heavy stresses upon a plane's structures during pullout, and this means that only aircraft designed for the job can be used safely. Also, the low altitude of release tends to make the aircraft an easy AA target especially during pullout.

Glide bombing is similar to dive bombing except that the attack angle is less than 60 degrees. This technique is better adapted to fighter-type aircraft which tend to develop excessive speeds in steep dives. Glide bombing is a high-speed attack and the bombs are released at an altitude of from 2,000 to 3,000 feet. The advantages over horizontal bombing include surprise and quick getaway. The disadvantages are that the bomb velocity is less than in dive bombing and AA vulnerability is greater than in dive bombing.

Skip Bombing

In skip or masthead bombing the plane usually attacks at less than 500 feet and the bomb is dropped so close to the target that computation is simple and accuracy high. If the target is a ship, the bomb is released to hit near the waterline just before the plane pulls up to pass over the target. Delay fuses are employed to give the aircraft time to clear the target. Surprise is highly desirable because the plane is exceedingly vulnerable to AA fire.

Toss Bombing

Toss bombing is a technique wherein the pilot dives his plane directly at the target for a short time and then pulls out. The bomb is released automatically during pullout. The pullout maneuver gives the bomb additional forward velocity so that it is tossed above the original line of sight and its trajectory intersects the original line of sight at the target.

In toss bombing, bombs can be released at higher altitudes than with dive or glide bombing. It necessitates only a short bombing run, but the plane is within effective AA range and is vulnerable during pullout.

Loft Bombing

Loft bombing is a means of making a low altitude, level approach to a target with a maneuver which keeps the aircraft well away from the target. The attack path requires that the aircraft pass over a landmark in direct line to the target at a specified altitude. After the elapse of a preset time interval, a pull-up is executed. The pull-up point is determined by the characteristics of the aircraft and must be such that the aircraft will pass through the release point at the desired climb angle. Equipment for this maneuver releases the bomb automatically when required flying characteristics have been met. For a more complete description or for figures showing this or any of the preceding bombing methods, you are referred once again to chapter 3 of this course.

A variation of loft bombing is the over-the-shoulder technique shown in figure 8–3. This method of attack may be chosen beforehand or may be used if the pilot misses the landmark. In the planned use of this technique the timing run is made as usual, but when the pull-up is made, the bomb is not released until the aircraft is near the top of the loop. Since the aircraft is in a several *g* turn, the bomb is thrown upwards, away from the aircraft, so that it falls on the target after the plane has pulled out and escaped. (See fig. 8–3.)

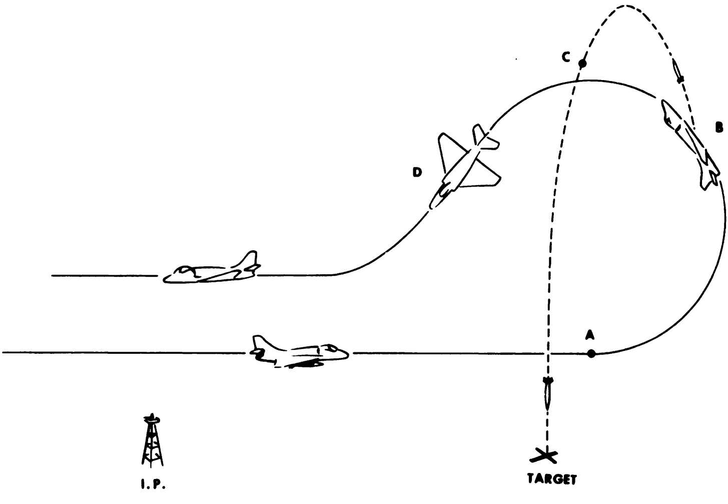


Figure 8–3.—The over-the-shoulder loft bomb attack.

Thus, in the over-the-shoulder attack, the timed run is started at I. P. and pull-up is made at point *A*, in figure 8–3. The bomb is released at point *B*. By the time the bomb reaches point *C*, the aircraft is at point *D* and has escaped.

LOW LEVEL BOMBING

In a consideration of the equipment used for bombing, we shall find, as in the other fire control equipment, there are two basic types—OPTICS and ELECTRONICS. We shall also see that there are relatively simple equipments used, in conjunction with radar, for determining the bomb release point by computing range only. There also exists amazingly complex equipment used, with or without radar, to determine the correct release point by considering all factors of the high altitude level bombing attack. Later, we will investigate the equipment used in solving the bombing problem and automatically releasing the bombs in other than level attacks.

Because the effects of wind and target motion are of little consideration, due to the short time of fall, the low altitude bombing problem is almost entirely one of range solution. This range problem is a relatively simple one. Employed in the solution of the problem by optical means are two general types of equipment; namely, the ANGLE OF DEPRESSION method, and the ANGULAR RATE method.

In the first type, the angle of depression, the altitude, groundspeed, and type of bomb used (ballistic coefficient) information is set into the sight. These factors cause a depression of the line of sight with relation to the flight path. The operator looks through the sight and manually (or electrically) releases the bombs when the line of sight crosses the target.

The same information is used in the second method. In the angular rate type, the operator rotates the tracking head to hold the line of sight on the target while the bombing run is being made. The computing mechanism of the sight measures the angular rate of rotation during the run and detects the rate which corresponds to the proper release point. The bombs will then be released at the proper instant automatically. Of the two, the angular rate type has proved to be much more accurate. The principles of the angular rate methods are incorporated in the Bombsight Mk 23.

Bombsight Mk 23 (Optical)

The Mk 23 bombsight was designed specifically for bombing in connection with antisubmarine warfare. It will compute the correct time of release for low level bombing attacks. The pilot flies a COLLISION course with the target in making a low level attack. Thus, the bombsight makes no computation for azimuth. Since trail and cross trail are negligible in bombing runs made at or below 500 feet, the Mk 23 sight has to make computation for the problem of range only. The Mk 23 sight may be used at altitudes of over 500 feet provided it is modified. However, most of its accuracy is lost when used in this manner.

The bombing method employed by the Mk 23 is shown in figure 8–4. In this figure, line *OO′* represents the flight path over the target *T* at an altitude *H*. The line *PT* is called the line of sight and the angle *a* is the angle of depression. Inspection of the figure shows that the angle *a* will be small when the bomber is at a far distance and will increase as the aircraft approaches the target. Also, the rate of change of the angle will be small at first and increase as the aircraft approaches the target.

Consider now the sight line *PT*. As the aircraft approaches, the sight line in the bombsight will have to be

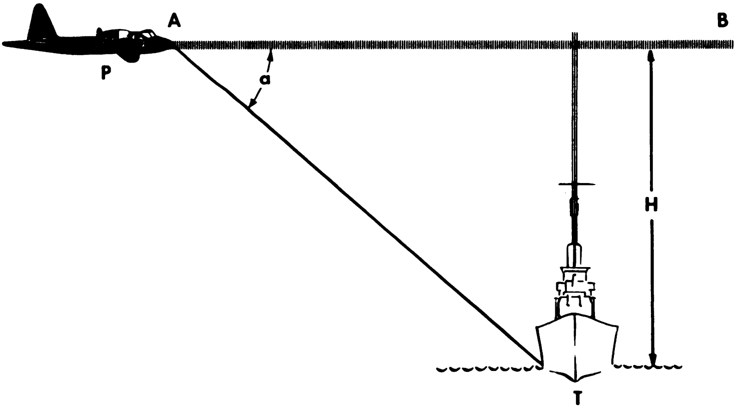


Figure 8–4.—Bombing method employed by the Mk 23 bombsight.

rotated to stay alined with *PT*. In order to hold the sight on the target, the operator must increase the rate of movement (rotational) of the sight head. At some point along the line *AB*, the bomb must be dropped in order to obtain a hit. The location of this point depends upon the altitude, the groundspeed of the bomber, and the ballistic coefficient of the bomb being used. Because of the definite relationship between the length of *AB* and the angular rate of change. the correct release point can be computed in terms of angular rate of change. Thus, when the rate of angular movement of the sight equals the computed angular rate, the bombs are automatically released.

COMPONENTS AND FUNCTIONS.—The Mk 23 bombsight consists of three major components: The sight unit, the control box, and the motor alternator. (See fig. 8–5.) The MOTOR ALTERNATOR supplies the 400-cycle, 3-phase alternating current to drive the gyro in the sight unit. A governor within the unit maintains the current within 0.5 percent of the rated value. This regulation is required for accurate operation of the gyro.

The CONTROL BOX serves as a junction point for the bombsight system's electrical and vacuum lines. Located on the front of the control box is the master ON-OFF switch, the TEST-BOMB switch, and the test lamp. A vacuum petcock is attached to one end of the control box. The control box also acts as a junction box for the microphone circuit.

The SIGHT UNIT (fig. 8–5) consists of a sight head, handle assembly, handgrips, and yoke assembly. The sight HEAD contains the computing mechanism, a Mk 9 gunsight for establishing the line of sight, and the following sight setting knobs: (1) Nomograph indexing, (2) height scale indexing knob, and (3) groundspeed knob. The handle assembly consists of the trunnion which supports the sight head in the yoke and the handgrips. The left handgrip contains the lip or throat microphone switch. The right handgrip contains the arming switch and searchlight switch, if one is used. The yoke assembly supports the sight head trunnions in bearings, which allows the sight head to pivot in the

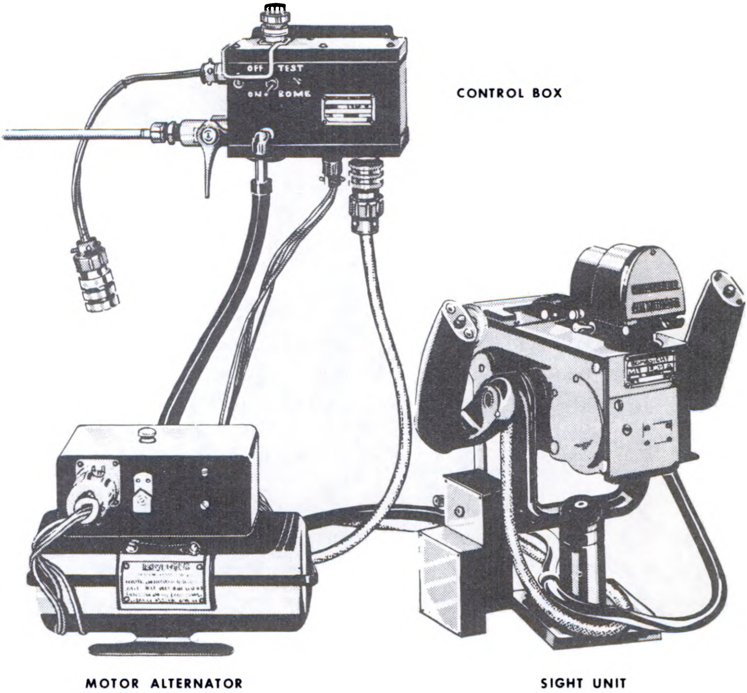


Figure 8–5.—Bombsight Mk 23.

vertical plane. The yoke also turns on its base to allow for horizontal pivot action.

Principles of operation.—For the proper operation of the Mk 23 type of bombsight, the following information must be either set in or measured by the equipment: Altitude, groundspeed, ballistics, and angular rate. The angular rate is measured by the gyro; while the other information is inserted by use of nomographs.

A nomograph is a chart or graph device used to determine the value of a dependent variable by alinement of the independent variable. In this equipment, nomographs are arranged in a series of *6* graphs on a clear film disk as shown in figure 8–6. Different disks are used for the various types of aircraft and bombs used with the Mk 23. More than one graph appears on each disk so that a train of bombs can be

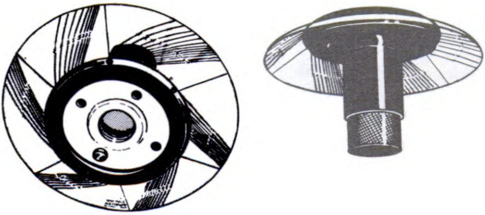


Figure 8–6.—Nomographs, Bombsight Mk 23.

dropped if desired. By selecting a particular graph on the disk, the bombardier can determine the point of impact of the first bomb of a train of bombs. Thus, the nomographs are computed to take care of the offsets which enter into the bombing problem.

Altitude information is incorporated by the adjustment of the height scale knob which controls a film containing the altitude indication and a cross hair as shown in figure 8–7. The groundspeed information is incorporated by the groundspeed knob. By alining the cross hairs and the estimated groundspeed lines, the proper height and speed setting for the bombing run are set into the equipment.

The function of the controls in the operation of the bombsight is shown in figure 8–8. Notice that the setting of the nomograph indexing knob controls, through a gear system, the tension on a calibrated spring. The actual setting of the

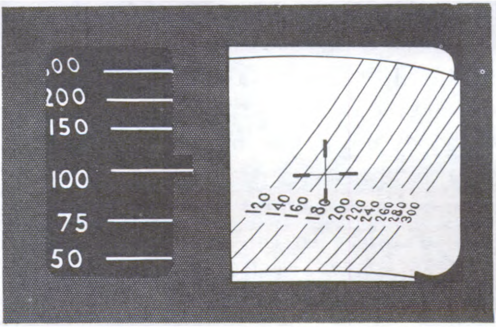


Figure 8–7.—Height scale pattern and nomographs for Bombsight Mk 23.

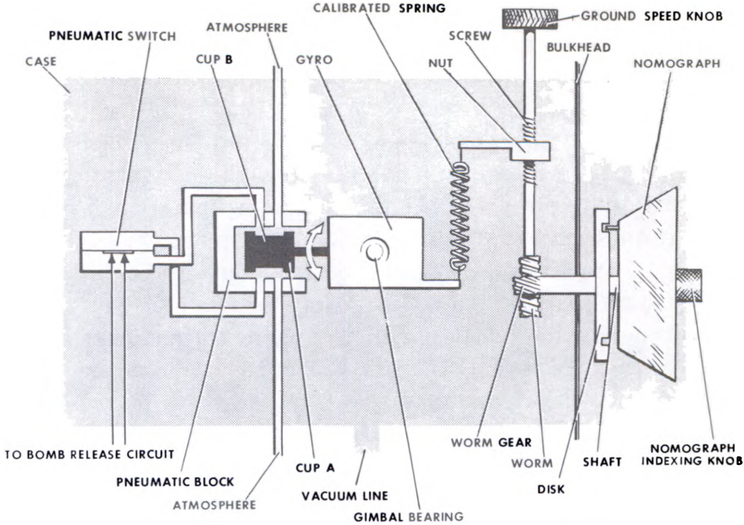


Figure 8–8.—Schematic diagram of Bombsight Mk 23.

nomograph will depend upon the groundspeed and height. Figure 8–8 shows the method of control exercised by the groundspeed knob. The height information is included by visual alinement of the cross hairs and the proper groundspeed line. By changing either the groundspeed line or the height will change the nomograph setting and thereby the spring tension.

The tension of the spring is exerted against the gyro which causes the attached cylinder to press against one side of the pneumatic block. (See fig. 8–8.) Now, when the PIPPER of the sight unit is held on a target with the arming switch closed, the sight will be depressed at a continually increasing angle. This causes the gyro to precess with a force directly proportional to the angular rate, and at the proper time this force will equal the tension value of the spring.

Each side of the pneumatic block is supplied with atmospheric pressure, the outer rims of the cups on each side of the cylinder are exposed to a vacuum of approximately four inches of mercury obtained from the aircraft engine. Areas within the cups are acted upon by pressures determined by the size of the openings between the cup rims and the surface of the pneumatic block. When the bombsight is at rest, the opening between the rim of cup *A* and the cylinder will be closed; thus cup *A* will be at atmospheric pressure. Because cup *A* is at atmospheric pressure and cup *B* is at some pressure between atmospheric and the partial vacuum, the pressures on the sides of the pneumatic switch are NOT equal. This results in the normally closed switch position.

During tracking the opening between cup *A* and the block will remain sealed until the gyro precessional torques equal the torque exerted by the spring minus the torques exerted by the pressure difference across the cups. When the gyro torque equals the spring torque, the pressures on the cups are equal.

Pressures on the cups are transmitted to the pneumatic switch chamber through passages containing restrictions. These restrictions together with the volume of the chamber prevent instantaneous transmission to the pneumatic switch of sudden changes in pressures. These sudden changes at the cups can be caused by sighting errors. Thus, this action smooths out irregularities in tracking. The nomograph setting for the spring is computed to cause equal pressures across the diaphragm of the switch when the angular rate required to obtain a hit is applied to the sight.

When the pressures on either side of the diaphragm are equal, the switch will open. Opening of the pneumatic switch actuates through a series of relays the circuits that release the bombs.

OPERATION.—The Mk 23 bombsight master switch is turned on first to permit the gyroscope to reach its proper operating speed. This should be done at least 15 minutes before using the sight. As soon as the gyroscope is up to operating speed, turn the vacuum source petcock to the ON position. Set the test selector switch to TEST. Press the arming switch and track an imaginary target. Lighting of the test lamp indicates that all circuits of the bombsight are in operating order. After the test is completed, turn off the vacuum petcock to prevent drawing dust into the tracking head.

The rheostat of the sight unit should be adjusted so that the reticle is visible against its background and the nomograph is properly illuminated. The correct nomograph for the desired attack should be selected, and the height index set for the altitude at which the bombing run is to be conducted. The velocity curve on the nomograph is selected which is nearest to that of the aircraft's groundspeed, and it is matched with the height index spot. When the test selector switch is in the TEST position, it forms a positive safety device to prevent premature release of the bomb stores if the arming switch and tracking head are actuated accidently.

During the actual bombing run, as soon as the target is sighted, the vacuum petcock is turned to the ON position. The test selector switch is placed in the BOMB position and a check is made of the altitude, speed, and nomograph settings. At the beginning of the bombing run, the reticle PIPPER should be placed on the target and tracking begun. When smooth tracking is established, the arming switch (located on the right handgrip) should be depressed. This switch is held in the depressed position until the bombs are released. Releasing of the bombs will occur automatically at the instant the proper rate is reached. At the end of the bombing run, the vacuum petcock should be turned OFF.

MODIFICATIONS.—The Mk 23 bombsight has been modified many times. In each case the purpose of the modification has been to better fit the basic bombsight to a particular installation. Mods 0 to 4 inclusive are quite similar with the differences being in the lens and tracking units.

The Mod 6 is used on aircraft where direct viewing is not possible. The bombsight is mounted in a yoke which is attached to a pad on top of a periscope. The bombsight and periscope are connected in such a manner that movement of the periscope results in movement of the bombsight. When using the Mod 6, the bombardier sights the target through the periscope instead of the bombsight.

The Mod 7 permits direct view sighting through the nose window of the aircraft. This insallation is used in patrol-type aircraft and has a hydraulic system installed to provide control of the searchlight. The searchlight is alined with the sight so that it is trained on the target at the same time. The Mod 9 differs from the Mod 7 in that the searchlight is electrically controlled.

The Mod 10 installation is unique, as the bombsight is installed in the nose turret. The Gunsight Mk 18 is used for establishing the sight line. To track the target, the turret is operated in elevation. This rotates the bombsight head at an angular rate as described previously. The control box of the Mod 10 has also been changed to the extent that a switch is provided for electrically energizing a vacuum pump to provide vacuum for the bombsight head.

MAINTENANCE.—Line maintenance of the Mk 23 bombsight and its different modifications should be limited to the routine operational CHECKS and ADJUSTMENTS, and to the REPLACEMENT of parts furnished either as operating spares or those to be found in the line maintenance spare parts set. Certain portions of the bombsight are accessible only through hermetically sealed access doors. For purposes of line maintenance these access doors (covers) should be considered permanently sealed. Any maintenance work involving the gyroscope compartment, pneumatic block compartment, or the pneumatic switch compartment should NOT be attempted.

Low Altitude Radar System

Soon after the developement of airborne radar, it was found that the radar displays did not present sufficient information for radar bombing. Targets could be located with sufficient accuracy in azimuth, but an accurate ranging and tracking system was needed. AN/APA–16 was then designed for attachment to radars to permit low altitude radar bombing.

PRINCIPLES OF OPERATION.—While intended primarily for use in bombing surface vessels, Aircraft Radar Equipment AN/APA–16 can be used against any target visible to the radar. This equipment provides the means for establishing the closing rate between a radar equipped aircraft and the surface target. It does this by furnishing a range mark for

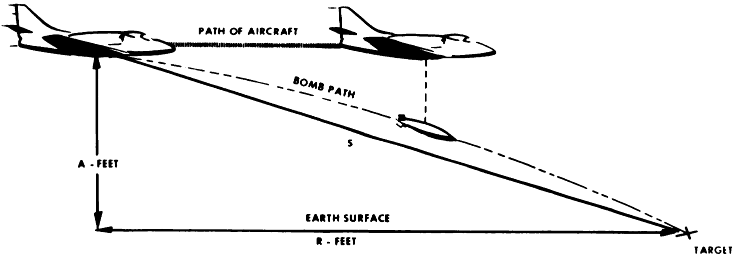


Figure 8–9.—Bomb path.

tracking the target echoes on the radar indicator. Information obtained by tracking plus altitude and ballistic information are fed to the computing circuits. Here the information is used to compute the release range and to release the bomb automatically at the proper point. The altitude and ballistic information are manually set in the equipment by the operator.

As shown in figure 8–9, the problem solved by AN/APA–16 is the determination of the proper distance *R* from the target to release the bombs. This distance *R* can be expressed in terms of two factors: The forward velocity (groundspeed) of the bomb, and the time of flight. The time of flight (forward) is the same as the time of fall, and the time of fall is dependent upon altitude, gravity, and ballistic factors.

By knowing or measuring altitude, gravity, ballistic factors, and groundspeed, the problem can be solved. Since gravity is known, altitude can be determined from altimeter readings, and ballistic information from tables; the factor that must be measured is the groundspeed. Thus, the operation of the AN/APA–16 is dependent upon obtaining the groundspeed or CLOSING RATE of the aircraft with respect to the target.

A search radar can determine the slant range *S* from aircraft to target. (See fig. 8–9.) If means are provided for tracking, that is, following the target echo as it moves down the radar indicator screen, the slant range closing rate at any particular time can be established. However, this rate decreases from point to point as the aircraft approaches the target, even though its ground velocity remains constant.

In general, therefore, it is necessary to convert this slant range into horizontal range to determine the horizontal closing rate. But if the bombing run is made at low altitude, the closing rate determined from slant range can be taken as the horizontal closing rate with only slight error, except when the aircraft is close to the target. Therefore, tracking operation is stopped when the target comes within a predetermined range which is dependent upon the altitude of the bombing run.

COMPONENTS AND FUNCTIONAL OPERATION.—This equipment consists of the three components shown in figures 8–10 and 8–12; namely, RANGE MARKER unit, CAPACITOR unit, and CONTROL unit. The equipment may also be employed to fire rockets when used with a rocket adapter unit (not shown). The CONTROL unit contains all the controls and switches necessary for the operation and calibration of the equipment. It also contains circuits which form an electrical computer used to determine the bomb release range. The control unit furnishes voltages which govern the operation of electronic circuits of the range marker unit. The value of these voltages is determined by data set up in the control unit.

The RANGE MARKER unit contains all of the electronic circuits of the equipment. It also contains the power supply used to furnish voltages to these electronic circuits and d-c voltage to the control unit. The CAPACITOR unit contains a specially constructed one-microfarad capacitor which functions as part of the rate-sweep generator circuit in the range

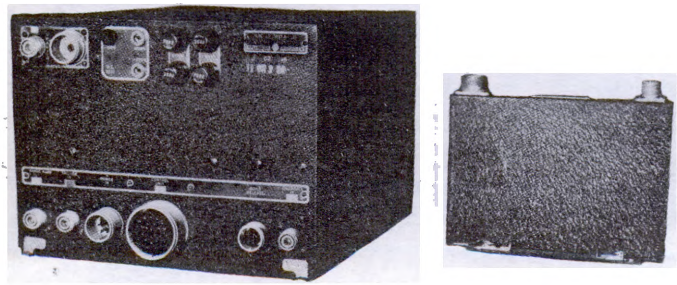


Figure 8–10.—Range marker and capacitor units.

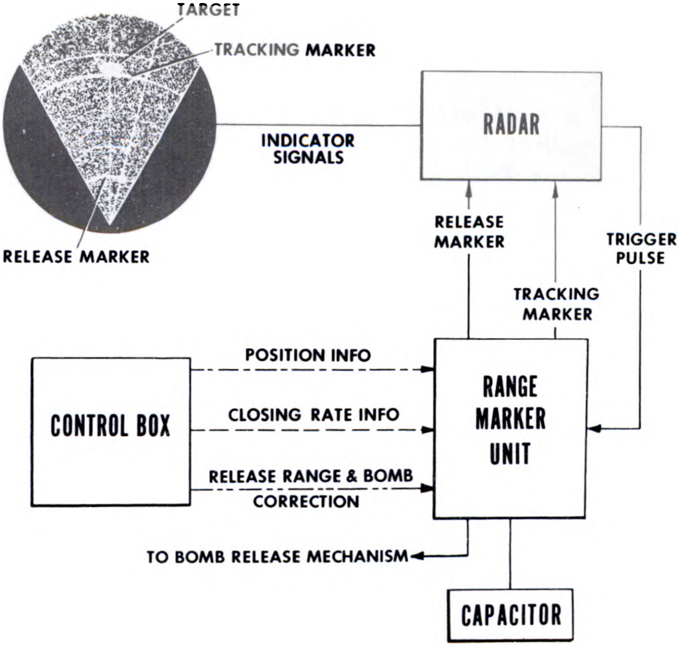


Figure 8–11.—Block diagram.

marker unit. This capacitor is housed separately to protect it from excessive heat.

The purpose of this equipment is to supply a tracking mark, a release mark, and a bomb release signal besides supplying the solution of the bombing problem. The information flow in accomplishing this is shown in figure 8–11. The radar supplies the trigger pulse which synchronizes the operation of this equipment and the radar.

The control unit by means of a voltage divider computer network provides position, closing rate, release range, and bomb correction information to the range marker unit. Position, closing rate, altitude, and bomb correction information is obtained by adjustment of the operator's controls. The release range information is computed from the input information.

The range marker unit receives this information and by means of electronic circuits develops and delivers the required output signals. These signals consist of the tracking marker, the release marker, and the bomb release signal. The tracking marker is fed to the radar indicator where the operator maintains coincidence between the target and the marker. The marker is placed on the target by the POSITION control and maintained in coincidence by simultaneous adjustment of both the POSITION and CLOSING RATE controls.

During the bombing run the tracking mark should remain on the target. At a predetermined range, the tracking is discontinued and no further adjustment should be made. Beyond this point, as the aircraft approaches the target, the target image gradually falls behind the range mark since the latter is moving down the indicator screen at a constant rate, while the former moves down at a diminishing rate in accordance with the rate of change of the slant range. To attempt to keep them together when close to the target will cause greater error.

Azimuth correction can and should be made until the airplane is near the release point. If the aircraft is slightly off course, the radar tends to show a rapid change in azimuth when the aircraft is close to the target. Small turns may correct this, but at very short range there is always the danger of overcorrection. It is essential that the aircraft is not turning when the bomb is released since this has a tendency to toss the bomb sideways away from the target.

Release of the bomb will be accomplished automatically when the tracking marker coincides with the release marker. An indication of the operation of the release mechanism is given to the operator by causing the lights on the control unit to momentarily go out.

OPERATING CONTROLS.—The operating controls are shown in figure 8–12. The POWER switch is used to energize the equipment while the DIMMER provides for manual control of the intensity of the dial illumination. The RANGE MARK control is no longer used and therefore should be kept in the closed position. When the SEARCH TRACK switch is in the SEARCH position, it disables the tracking

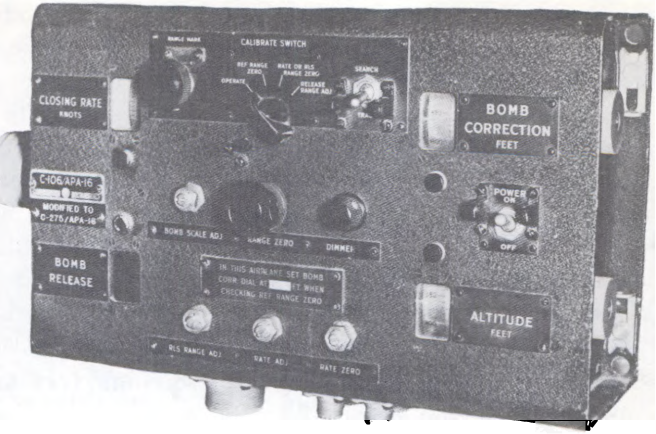


Figure 8–12.—Control unit.

circuits and opens the circuit through the release relay. When on TRACK, this switch enables both the tracking circuit and the release circuit.

The CLOSING RATE knob is used to insert the rate information by controlling the setting of a potentiometer. An associated dial, calibrated in knots, is visible to the operator. The POSITION knob, as its name implies, is used to determine the position of the tracking marker by controlling the setting of the position potentiometer. If coincidence between the marker and the target is lost, both the POSITION and CLOSING RATE knobs are adjusted simultaneously. These knobs are mounted in such a manner that dual adjustments may be made with ease.

The BOMB CORRECTION knob also controls a potentiometer for the inclusion of ballistics information into the solution of the problem. Its associated dial is viewed from the front as is the dial of the ALTITUDE control. Altitude information is set in by controlling the altitude dial with the ALTITUDE control. The value to be manually set in is determined by other instruments in the airplane. The remaining controls on the control unit are calibrating controls and will not be discussed here.

Maintenance.—In the maintenance of this equipment, the degree of maintenance you will be called upon to perform will vary with such factors as availability of experienced technicians, squadron or unit policy, the needs of the service, and your knowledge and experience. Of course, any faulty operation should be corrected by means of a systematic troubleshooting procedure followed by readjustment and/or repairs or replacements of faulty parts. To aid in determining the minimum performance standards for this equipment, the following preflight or operational check is given:

1. Make sure that the equipment is securely mounted; all cables are properly in place; and that connectors are tight. The latter is very important since loose connectors are a common source of trouble.
2. Turn on the associated radar.
3. With a d-c meter of at least 1,000 ohms per volt sensitivity, check the voltages at the jacks provided at the front of the range marker unit. These voltages should be approximately the values marked at the jacks.
4. Set the SEARCH–TRACK switch on SEARCH and adjust the DIMMER control to a comfortable level.
5. Adjust the radar indicator focus and brillance controls in the usual manner to obtain the desired image definition and intensity.
6. Set the POSITION, CLOSING RATE, and ALTITUDE controls to their maximum positions.
7. Turn the SEARCH–TRACK switch to TRACK while observing the pattern on the screen. The track marker should move down the screen. When it reaches the release marker, the lights in the control unit should go out.
8. After the lights in the control unit go out, return the SEARCH–TRACK switch to SEARCH. Secure the equipment.

At prescribed intervals it will be necessary to calibrate this equipment. The procedure to be followed and the equipment to be used are given in the service manual for this equipment. There you will also find the method to be followed in lubrication of the moving parts.

HIGH LEVEL BOMB DIRECTOR

The bomb director used in the solution of the high level bombing problem is an amazingly intricate piece of equipment. Nevertheless, it has been designed for ease in service and maintenance. It also exemplifies the reason for the requirement that the AQ be one of the highest trained ratings in the Navy. Of course to have highly trained men, you must begin with a high caliber of men—men who take pride in answering the maintenance challenge put forth by this type of equipment. Successful maintenance and repair of equipment of this type represents an accomplishment not to be taken lightly.

The high level bomb director is a radar-optical bombing system. Its primary function is PRECISION bombing from high-speed, high-altitude aircraft. The equipment can also be used for SEARCH and NAVIGATION.

On a bombing run, the operator merely synchronizes on the aim point by using a tracking lever. This aim point may or may not be offset from the target. By synchronizing on the aim point the operator adds the necessary information to that initially set in for the equipment to solve the bombing problem. At the proper time, the equipment will automatically open the bomb bay doors, release the bomb load, and then close the bomb bay doors in sequence.

On any such mission, the tracking recorder may also be operated to obtain a photographic record of the radar or optical presentation. Such a record can then be used as accurate reconnaissance for future operation.

The numerous features included in this system of bomb direction broadens the scope of operation tremendously. However, in spite of this complexity of function, the system is easy to operate and has been designed to simplify installation and maintenance.

Advantages

Some of the outstanding characteristics incorporated in this type of equipment include:

1. Either optical or radar inspection of area by use of both a periscope and a radar antenna.
2. Stabilization of both the optical line of sight and the radar beam against airplane rotations. This is to permit tracking from a stable reference.
3. Precision tracking is performed automatically after the operator has twice positioned the crosslines on the aim point.
4. If a stationary target is hidden or obscure, offset bombing is possible.
5. Evasive maneuvers can be performed by the pilot during the bombing run.
6. Automatic control of the aircraft by the system during a bombing run, if desired.
7. Automatic opening and closing of bomb bay doors plus release of bomb load.
8. A ground position indicator automatically furnishes navigational data in the form of latitude and longitude of aircraft present ground position.

Block Diagram

The solution of the general high level bombing problem is discussed in chapter 3 of this course. Basically it consists of determining (1) the POSITION of the target with respect to the aircraft at every instant, and (2) WHERE the bomb would hit if released at any given instant. By knowing this information it is possible to determine where to release the bomb to hit the designated target. The position of the target is continuously determined by TRACKING. Where the bomb will hit is continuously computed from bomb BALLISTIC DATA.

Thus, the problem is simplified to TRACKING and determining TRAJECTORY. Let us now investigate the manner in which the bomb director solves this problem. Figure 8–13 shows the information flow between the major systems of the bomb director.

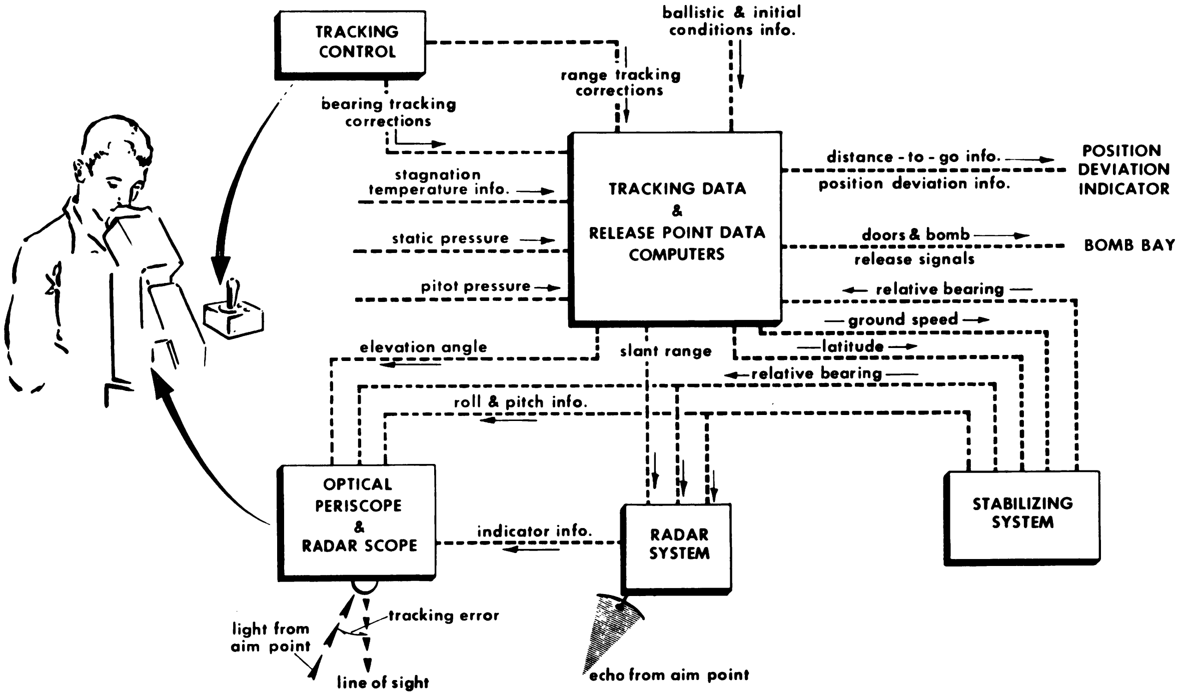


Figure 8—13.—Block diagram of high level bomb director.

Either the optical or radar system, in conjunction with the tracking data computing and the stabilizing systems, continuously TRACKS an aim point. The release point data computing system continuously computes the IMPACT POINT of the bomb, the course to fly, and the bomb release point.

The optical system is the sighting element for optical tracking, and the radar system is the sighting element for radar tracking. The optical system establishes the line of sight and indicates any difference between the line of sight and line to aim point. (See fig. 8–13.) This difference is indicated as a displacement (tracking error) of the aim point image from the intersection of the optical crosslines.

The radar system, as all radars, measures slant range and relative bearing of the aim point. Any unaltered radar range measurement is slant range and NOT surface range from beneath the aircraft to the surface target. This radar system also received COMPUTED values of slant and relative bearing from the tracking data computing and stabilizing systems, respectively. Any differences between the measured and computed values are indicated as a displacement of the aim point image from the intersection of the radar crosslines. Thus, the operator can observe needed corrections either by radar or optics.

The operator, observing either optical or radar presentation, simultaneously corrects both the optical and radar system in range and azimuth by keeping the aim point image at the intersection of the crosslines. He makes these corrections by movement of the tracking control. (See fig. 8–13.)

It is appropriate to point out that the radar does not feed to the computer a voltage representing slant range. The radar measurement of range information is communicated to the system by the placement of the target on the scope. The operator completes the control loop by moving the tracking lever until the crosslines coincide with the aim point.

The stabilizing system maintains the radar and optical lines of sight FIXED in space despite movement of the aircraft about its roll, pitch, and azimuth axes. This stabilization is accomplished by a system of three gyros which produce a stable platform and reference direction. It also measures aircraft rotations about these stable axes. The measured values of roll, pitch, and relative bearing are fed to the optical and radar systems. As shown in figure 8–13, the measured value of relative bearing is also fed to the release point computing system. Thus, tracking can be accomplished from a stable reference.

The tracking data computing system generates correct tracking data from the operator's tracking correction input in conjunction with inputs of aim point altitude, stagnation (still air) temperature, and pitot and static pressures. The computing system generates this correct tracking by determining groundspeed which is the rate of relative airplane motion with respect to the aim point. Groundspeed is also the sum of airspeed and wind. The computer determines airspeed from the automatic inputs of static and pitot pressure and stagnation temperature. Wind is determined from the sum of the tracking corrections introduced by the operator or bombardier. Thus, precision tracking is performed automatically after the operator has TWICE positioned the crosslines on the aim point.

From the groundspeed and wind information the computer continuously generates the values for the aim point position. These values (namely range, bearing, and elevation) are then fed to the radar and periscope. (See fig. 8–13.) The purpose is to establish the crosslines for comparison with the information received from the aim point.

If the crosslines do not stay on the aim point image, the operator introduces both position and rate tracking corrections to adjust the generated values to the actual values. The primary reason for the cross lines leaving the air point is wind effect. By these corrections, the position of the aim point and its relative motion (groundspeed) are set up in the tracking loop through the tracking process. The COMPUTED tracking data are fed to the release-point data computing system for use in computing the course to fly and the release point. Thereby, the first of our conditions (tracking or continuous position of target) has been met.

Groundspeed and latitude are fed to the stabilizing system for earth rotation corrections. True bearing is fed to the same system for the computation of relative bearing. Slant range is fed to the radar system for comparison of computed slant range with the observed slant range. Comparison of the computed elevation angle with the observed aim point elevation angle is obtained by feeding the elevation angle to the optical system.

The release-point data computing system continuously computes the position of the IMPACT POINT, the course for the airplane to fly, and the point of bomb release. The system receives tracking data from the tracking data computing system and manual inputs. These manual inputs consist of target altitude above sea level, bomb ballistic setting, bomb spacing, and number of bombs. Thus, the second condition (continuous information of where the bomb will hit or impact point) has been met.

By knowing (1) the POSITION of the target with respect to the aircraft at every instant, and (2) WHERE the bomb would hit if released at any given instant, it is possible to determine where to release the bomb to hit the designated target. The computing system performs this determination.

The release-point data computing system also computes position deviation indication (course changes) and transmits this information to the pilot and autopilot to bring the airplane to the correct course and to indicate the distance to the release point. In addition, the system computes signals which automatically open the bomb bay doors, drop the bomb or stick of bombs at the release point, and close the doors at the end of the run.

When offset bombing is used, the release-point data computing system also receives inputs of the offset distance and the bearing between the aim point and the target. Using these inputs, the system determines target data before solving the bombing problem.

Thus, the bomb director operates as a loop where—

1. Tracking corrections based on observation of either the optical or radar presentation are made by the operator and fed to the tracking data computing system.

2. The tracking data computing system determines tracking data for the bomb director and feeds this information back to the radar and optical systems directly and through the stabilizing system.

3. The tracking data drive the optical or radar system, and the operator observes the presentations to determine whether this information is correct.

4. The information obtained from tracking is also fed to the release-point data computing system along with inputs of bomb ballistics to compute the course to fly at release and the position of the release point.

Another function of the computing system is the generation of ground position value of the airplane for use in navigation. The process of obtaining this navigational information is the use of groundspeed, course information, and initial latitude and longitude values. The groundspeed and course information (direction) is obtained during the tracking process. The initial latitude and longitude information is manually set by the operator. (See fig. 8–13.) From all this information, the computing systems continuously generate the latitude and longitude of the ground position. These ground position values are accurate as long as groundspeed and course are computed correctly through the tracking process.

Components and Functions

The location of most components of this equipment depends on the type of airplane in which the bomb director is installed. Some of the components because of their function must be accessible to the operator or the pilot. For example, the tracking control must be close to the operator while the position deviation indicator must be visible to the pilot. A description of the major components, but not all the components, is given in the following paragraphs.

COMPUTER.—The computer is the major computing element of the bomb director. It solves the bombing problem and computes navigation data. The computer performs the following major functions:

1. Measures true airspeed and altitude above sea level.

2. Computes groundspeed.
3. Generates airplane latitude and longitude.
4. Generates aim point bearing, slant range, and elevation angle.
5. Computes the PDI angle and distance-to-go; these are indicated on the PDI meter.
6. Computes trail and time of fall.
7. Provides signals for operating the bomb bay doors and for dropping the bombs. The number of bombs and spacing are set and indicated on the intervalometer.

The computer consists of a front panel on which is located the majority of the operating controls and indicators, a structural frame, and a number of interconnected mechanical and electromechanical plug-in subcomponents.

CONTROL PANEL.—Numerous switches and knobs on the front of the control panel perform the following major functions:

1. Control power to all components of the equipment.
2. Select radar or optical presentations.
3. Select the type of radar presentation and adjust radar operation.
4. Control the operation of the gyros, periscope, and tracking recorder. These controls and their operation are described in detail in the appropriate operating manuals.

Inside the housing of this unit is a chassis on which push-button type circuit breakers are mounted. They control the power to various units. These circuit breakers are equipped with overload devices to protect the main circuits against excessive currents. Tripped circuit breakers may be reset by pushing the applicable buttons located on the rear panel of the bomb director.

TRACKING CONTROL.—The tracking control is used to introduce range and bearing tracking corrections into the computer. It contains a tracking lever which the operator uses to center the radar or optical crosslines on the aim point image. By depressing the rate button, inset in the top of the tracking lever, he can also introduce rate corrections. A solenoid operated plate prevents the rate button from being depressed unless specified conditions exist.

PERISCOPE.—The periscope is located at the operator's position in such a manner that it will receive light from the aim point. It contains the major portion of the optical elements. In the periscope the optical line of sight is positioned and stabilized by inputs from the stabilizing system and computer.

The optical system also receives radar presentations from the radar indicator. The operator selects the type of operation, either optical or radar, by means of a function switch located on the control panel. The optical system also transmits either the optical or radar presentations to the tracking recorder. The tracking recorder consists of a camera which photographs the optical or radar display singly or in series.

POSITION DEVIATION INDICATOR.—The Position Deviation Indicator which is mounted on the pilot's instrument panel is his source of information during the bombing run. This unit has two concentric dials on its front face. A pointer and one of the dials indicate the PDI angle in degrees. Two pointers and the inner dial indicate the distance-to-go in nautical miles. Both of these values are received from the computer.

STABILIZING ASSEMBLY.—The stabilizing assembly establishes a stable reference for radar and optical tracking. Roll, pitch, and course changes of the aircraft are measured by three gyros. Roll and pitch are transmitted to the antenna and periscope system for horizontal stabilization. Magnetic north is transmitted to the computer to stabilize bearing data.

RADAR.—The radar performs the usual function of a radar system; that is, the transmission and reception of RF energy which conveys the position of the target. Besides being used for bombing missions, the radar can be utilized for searching and navigation.

Operation

While there are many controls appearing on units of the high level bomb director, only a few of them plus the tracking lever are used during a bombing run. The other controls either introduce certain predetermined values, such as bomb ballistics and target information prior to the bombing run, or facilitate the operator's duties. For example, such controls as CONTRAST, DIFFERENTIAL GAIN, BRILLIANCE, and so forth, while not affecting the accuracy of the system, do aid the operator by giving him the means of obtaining the clearest possible radar presentation.

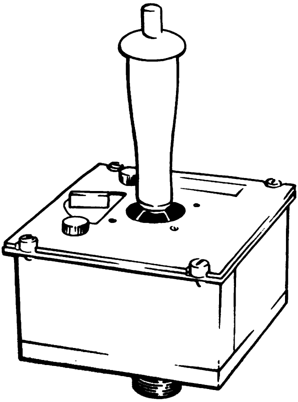


Figure 8–14.—Tracking lever.

Little skill is required to operate the system. On a bombing run the operator must use the tracking lever (fig. 8–14) to position the cross hairs on the aim point. In addition, he must engage the Position Deviation Indicator and the automatic release switches. Thereafter, by merely putting the cross hairs back on the aim point if they should drift, the operator completes his task of figuratively pointing out the aim point to the computer. The computer will then establish the correct point of release and indicate the proper course and distance-to-go. The computer automatically adjusts the point of release to match changes in airspeed and rate of climb and dive within very broad limits.

By constantly measuring these important flight factors and correcting the bombing solution accordingly, the bomb director relieves the pilot of maintaining close coordination with the operator and enables him to take evasive action during the bombing run. The pilot is only required to have the Position Deviation Indicator direction pointer at zero, when the PDI distance-to-go pointers reach zero (release point). While the direction pointer lies between the two distance-to-go pointers. the pilot knows that he will be able to center it before reaching the release point.

Displacement corrections are made by pushing the tracking lever in the direction in which the cross hairs are desired to move. Simultaneous rate corrections may be made by halfway depressing the red rate button on top of the lever. However, the rate button mechanism is designed so that it cannot be depressed until one displacement in azimuth and range under tracking conditions has been made, thereby precluding the possibility of introducing incorrect rates.

Once depressed for a rate correction, the button will remain locked until it is fully depressed, when it will unlock and return to its fully extended position. It is again available to the operator for displacement corrections, if and when they are needed. This positive sequence of setting-in displacement and rate corrections minimizes the possibilities of error and makes the operator's job practically foolproof.

The overall usefulness of the equipment during the entire mission, the simplification of operation and the minimized dependence of the pilot on the operator, and vice versa, results in maximum utilization of the equipment and maximum accuracy.

The several features of the equipment that provide automatic performance of most functions greatly reduce the operational responsibilities of the operators. The many knobs and counters of the bomb director provide for varied and flexible operation of the system, but they are used only infrequently for making initial settings, for changing the mode of operation of the system, and for making adjustments. When the initial settings and adjustments have been made and the condition of operation has been selected, the operator need concern himself with only a very small number of these controls.

Maintenance

This type of bomb director has been designed so that each of the separately installed components is interchangeable in the aircraft without any alinement or adjustments. The more intricate components consist of interchangeable subcomponents. For example, the antenna feed horn and dish as well as the entire antenna are interchangeable without alinement. The periscope assembly as well as its separate upper, middle, and lower sections also may be replaced without alinement.

If the system fails because of a faulty component, the component found to be the cause of the failure can be replaced in the plane by a satisfactory one obtained from stock. Defective parts or subcomponents can be repaired or rebuilt at a convenient time and place.

The mechanical components used in the equipment have been engineered for interchangeability during maintenance. As an example, the input and output shaft couplings of the subcomponents are alined to match their mating shaft on the frame.

Coupling pins and slots are located in manufacture so that interconnecting shafts, gears, and push-pull rods represent specified values at specified angular or linear displacements. Prior to installation, the alinement settings are made on the individual subcomponents by use of locking pins. These pins can be inserted in the appropriate alinement hole when correct positioning is obtained.

The outstanding maintenance feature for the equipment is interchangeability, without requiring individual calibration or necessitating system alinement or adjustments. This is true not only of subcomponents but of complete components. As a result, a minimum stock of spare parts is needed, and a higher percentage of equipment availability is achieved.

As fire control technicians responsible for the maintenance of this type of equipment, the need for knowing the function of each major component should be apparent. It is also important for you to be very familiar with the location of components in the aircraft as well as the cables connecting units. You need NOT know the operating principles of each electronic circuit or mechanical device to keep the high level bomb director in an "up" condition.

LOFT BOMBING EQUIPMENT

Loft bombing has furnished the best solution to the problem of dropping powerful high explosive bombs from a low altitude without endangering the dropping aircraft. Dive, toss, and glide bombing methods are inadequate for such low altitude bombing because they place the aircraft in a position where it is vulnerable both to the bomb blast and the antiaircraft fire beyond the target.

The loft bombing attack uses the high speed of modern fighters and light bombers to throw the bomb from the release point to the target giving the aircraft an opportunity to escape. The entire loft bombing attack is made at a low altitude, making it possible to evade radar tracking, and the aircraft can be well clear of the blast when the bomb goes off. If there is a low overcast, the aircraft can come in just under it and pull up into the clouds. The necessary computations and release signals for this attack are developed in the loft bombing equipment.

One type of equipment used in the solution of the loft bombing problem is the type we shall identify as the Armament Control System Aero 18 A/B/C (LABS) equipment. The equipment performs a dual purpose. It is used for both loft bombing and over-the-shoulder bombing. Since a discussion of these bombing techniques has been given previously, our first objective is the principles of operation of the equipment.

Principles of Operation

As we have pointed out in chapter 3 of this course, the loft bombing attack is essentially a precalculated problem. Before starting the mission, the pilot must have accurately located the target and a suitable identification point (landmark) from charts and photographs for use as the initial point. An approach altitude and speed are chosen. Finally, tables are consulted for the bomb and aircraft characteristics.

From these tables the bomb release angle is determined for the particular mission. The release angle is the angle at which the particular bomb should be released to obtain a hit. This information is set into the equipment. Also the run-in time between the initial point and pull-up is determined and set into the equipment. Compensations are included for the effects of wind in these computations.

Among the factors that enter into these computations is vertical acceleration. The value of vertical acceleration used in the determination of the release angle must be maintained by the aircraft. This is accomplished by the pilot keeping the acceleration (horizontal) needle centered during pull-up.

At this point, let us digress to refresh you on the meaning of three terms common to aircraft; namely, pitch, yaw, and roll. There are three axes about which an aircraft will rotate; these are the lateral, vertical, and longitudinal axes. (See fig. 8–15.) The LATERAL axis is an imaginary line which runs from wingtip to wingtip through the center of gravity.

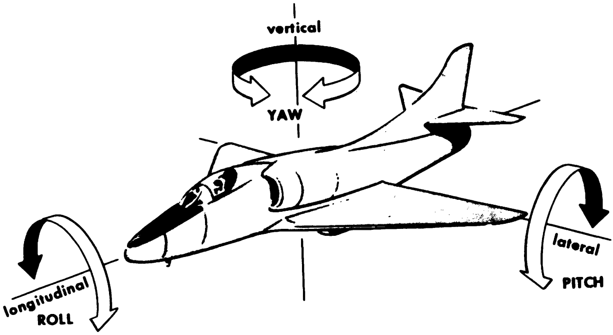


Figure 8–15.—Aircraft axes.

Rotation about this axis is called PITCH. An imaginary line which runs through the center of gravity from top to bottom is called the VERTICAL axis. Rotation about this axis is called YAW. The LONGITUDINAL axis is an imaginary line which runs through the center of gravity from nose to tail. ROLL is the name applied to rotation about this axis.

As the aircraft follows the prescribed path during run-in, the equipment will supply the pilot with aircraft ROLL and PITCH information. This information is obtained from a gyro and presented on a dual-movement meter indicator. The purpose in providing this roll and pitch information is to aid the pilot in maintaining the prescribed flight path. If an aircraft assumes a roll or pitch attitude, its flight path will differ from the path when the aircraft is straight and level. The pilot actually prevents rolling or pitching by keeping both the vertical and horizontal needles centered. The vertical pointer indicates ROLL angle while the horizontal pointer registers PITCH angle.

At a preset time, the equipment will signal the pilot by means of a light when to begin the pull-up. At the same time the meter indicator will automatically change its presentation to YAW-ROLL and ACCELERATION information. Changing of the meter indications and lighting of the light is controlled by the actions of a timer.

The purpose in presenting yaw and roll information is that if the aircraft is yawing or rolling at bomb release, the result will be a change in bomb trajectory. The yaw-roll information is obtained from a gyro. Since yaw and roll error require the same type of corrective motion, both are indicated on one pointer.

The horizontal pointer at this time will show vertical acceleration or *g*'s. The number of *g*'s required for the desired pull-up is determined from the tables and graphs. This information is set into the equipment beforehand, so that the horizontal needle will remain centered as long as the correct number of *g*'s are maintained during pull-up. The vertical acceleration information is provided by an accelerometer.

When the aircraft reaches the preset pitch angle, the light goes out and the bomb is automatically released and thrown towards the target. The pilot then may make any desired maneuver to leave the target area.

Function and Operation

Using the block diagram shown in figure 8–16, let us now consider the function and operation of the various components and the flow of information. The operation of the equipment starts when the pilot presses his PICKLE switch as he passes over the INITIAL POINT. In any type of run, the PICKLE switch must be held down until the bomb is dropped. If released before this time, the sequence is stopped and a new attack must be made. Depressing the PICKLE switch starts a timer mechanism and results in turning OFF the indicator light.

THE TIMER.—The timer is mounted in the cockpit, where it may be set by the pilot either before takeoff or while airborne. It controls the interval between pressing the pickle switch and pull-up maneuver. At the end of the preset time interval the timer originates the signal that results in turning ON the light and in changing the indicator presentation.

RELAY BOX.—The relay box contains a system of relays, fuses, bridge circuits, and potentiometers. Its purpose is to receive the control information from the timer and the angle selector switch (mode control). The relay box then transfers this information into the proper signals that result in the desired mode of operation.

VERTICAL GYRO.—The vertical gyro serves as a vertical reference for the system and determines when the aircraft reaches the preset bomb release angle. This gyro, mounted in universal gimbals, can move 360 degrees in pitch and plus or minus approximately 90 degrees in roll. True to gyroscopic action, this gyro will hold a true vertical position.

Indicating devices are mounted on the ROLL and PITCH axes of this gyro. These devices send information to the dual pointer indicator. This information provides pointer deflections proportional to the aircraft's changes in the roll and pitch axes.

The correct bomb release angle is set before the mission on two movable calibrated switches on the pitch axis of the gyro. The switches are set by dials under screwcaps on the top corners of the gyro case. One of the switches will pro-

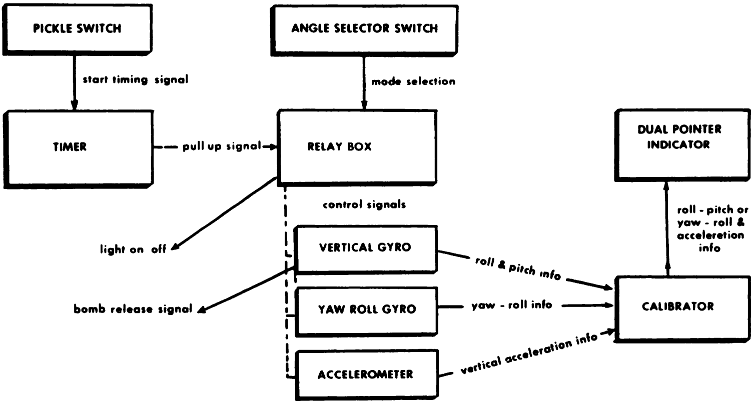


Figure 8–16.—Block diagram of ACS–LAB system.

vide the release pulse for LOFT operation, while the other can be set for OVER-THE-SHOULDER bombing. The switch used for a particular mission is determined by the angle selector switch via the relay box.

YAW-ROLL GYRO.—The yaw-roll gyro is mounted with its axis parallel to the LATERAL axis of the aircraft, so that it will sense YAW and ROLL motion. Sensing devices are mounted on both axes thereby producing yaw and roll signals. These signals are fed to the calibrator where they are converted into signals for the control of the VERTICAL pointer of the indicator during pull-up.

ACCELEROMETER.—The accelerometer is an oil-immersed, spring-suspended mass, which senses vertical acceleration, or number of *g*'s. During pull-up, a signal proportional to the acceleration detected is fed through the calibrator to the indicator. Here it is used to control deflection of the HORIZONTAL pointer.

INDICATOR.—The indicator is a dual pointer meter. During the timing run-in portion of the attack, where straight and level flight is required, the vertical pointer indicates roll angle, and the horizontal pointer registers pitch angle. This information comes from the vertical gyro.

During pull-up the pointer circuits are automatically switched. The horizontal pointer will now show vertical acceleration and the vertical pointer shows both yaw and roll.

Even though the presentation changes during the attack, the pilot's job is the same; keeping both pointers centered. A MAN Y/R button in the cockpit permits the pilot to manually transfer the indicator to acceleration and yaw-roll presentations before pull-up if this is desired.

CALIBRATOR.—The calibrator contains the circuits and relay networks that are employed during the pull-up portion of the attack. One circuit receives the yaw and roll signals and provides a resultant composite signal for control of the VERTICAL pointer. The calibrator also energizes the lamp during pull-up.

Operation

The operation of this system requires a minimum of controls. The major consideration for the pilot is to follow the planned attack. Three modes of operation are possible with this type of equipment; namely, LOFT, TIMED O/S (over-the-shoulder), and INST O/S.

The first of these is selected by placing the angle selector switch in the LOFT position and turning ON the equipment. The light will turn ON and the indicator will provide roll and pitch information.

When the aircraft passes over the initial point, the PICKLE button is depressed to start the timed run and the light will go OFF. When the light turns back ON, the timed run has been completed and pull-up should be started. At this point, the indicator presents yaw-roll and acceleration information.

When the aircraft reaches the selected angle, the indicator light will turn OFF signifying automatic bomb release. After bomb release, releasing the PICKLE button transfers the indication back to roll-pitch information. It is possible for the pilot to select yaw-roll and acceleration information before pull-up by energizing a MAN Y/R button.

The over-the-shoulder technique is a variation of loft bombing. This may be chosen beforehand or may be used if the pilot misses the initial point. When done normally, the angle selector switch in the cockpit is set to TIMED O/S. This selects the proper switch on the vertical gyro. The timing run is made as usual, but when pull-up is made, the bomb is not released until the aircraft is near the top of the loop. Since the aircraft is in a several *g* turn, the bomb is thrown upwards away from the aircraft, so it falls on the target after the plane has pulled out and escaped.

When the pilot misses his initial point, he will set the angle selector switch to INST O/S. He then presses his PICKLE switch and pulls up at the instant he passes over the target. The bomb will be released on the top of the loop as before.

Maintenance

The maintenance of this equipment is for the most part limited for squadron personnel to inspections, adjustments, calibrations, and replacement of units. While some troubleshooting is possible, squadron personnel should not attempt to repair components of the system. Covers should not be removed from the vertical and yaw-roll gyros. Further, do not attempt to disassemble the timer, indicator, or accelerometer, since this will result in damage to the units. Also do not adjust the timer dial when the PICKLE button is depressed since this will cause permanent damage to the timer.

Warning: When conducting a ground check, the bomb racks must be empty or the bomb rack selector switch in the OFF position.

Procedures for performing the periodic inspections and adjustments will be found in appropriate service manuals. It is interesting to note that these manuals state that no lubrication of the system components should be attempted by squadron maintenance. All components believed to be in need of lubrication must be returned to overhaul depots and replacement units installed in their place.

QUIZ

1. If a bomb were dropped in a vacuum, at the instant of impact the bombing aircraft would be
   a. above and aft of the point of impact
   b. directly above the point of impact
   c. above and beyond the point of impact
   d. beyond the point of impact by certain amount of trail
2. The horizontal distance between the points of impact of the actual trajectory and the vacuum trajectory is called
   a. ground range
   b. cross trail
   c. ground lag
   d. trail
3. The ground distance from point of impact to true course is referred to as
   a. trail
   b. drift
   c. cross trail
   d. lag
4. Low level horizontal bombing problems are usually solved by what method?
   a. Angular rate of depression
   b. Range angle
   c. Angle of depression
   d. Range angle rate
5. The primary difference between a dive bombing run and glide bombing run is the
   a. release altitude
   b. dive angle
   c. speed
   d. length of run
6. Toss, loft, and over-the-shoulder bombing all require
   a. the same dive angle
   b. the same length of run
   c. horizontal level flight to release
   d. a definite pull-up maneuver to release
7. The Mk 23 bombsight was designed for use with altitudes up to
   a. 50 feet
   b. 5,000 feet
   c. 500 feet
   d. 350 feet

8. The three major components of the Mk 23 bombsight are
   a. sight unit, control box, and motor alternator
   b. sight unit, vacuum regulator, and motor alternator
   c. control box, gyro unit, and motor alternator
   d. sight unit, control box, and centrifugal governor
9. The factors set into the Mk 23 bombsight are
   a. altitude, groundspeed, and angular rate
   b. altitude, groundspeed, and ballistics
   c. altitude, airspeed, and ballistics
   d. range, groundspeed, and altitude
10. In order for the gyro in the Mk 23 bombsight to precess and cause the bombs to be released, it must overcome
   a. friction
   b. the vacuum
   c. spring tension
   d. atmospheric pressure
11. When using the Mk 23 Mod 10 bombsight, the sight line is established by the
   a. Mk 20 illuminated sight
   b. Mk 8 illuminated sight
   c. Mk 41 periscope
   d. Mk 18 gunsight
12. In the high level bomb director the rate button is located on the
   a. control box
   b. computer front panel
   c. pilot's throttle
   d. tracking lever
13. In order to perform automatic precision tracking, the operator must position the crosslines on the aim point at least
   a. one time
   b. two times
   c. three times
   d. four times
14. Offset bombing is used to
   a. increase the range of the bomb director
   b. enable high altitude runs to be made
   c. stabilize crosslines on the target
   d. enable runs to be made on hidden or obscure targets
15. Navigational aid is furnished to the pilot by the
   a. tracking recorder
   b. ground position indicator
   c. stabilization system
   d. radar indicator

16. Information supplied to the bombsight from which the bomb trajectory can be determined is called
    a. ballistic data
    b. tracking information
    c. ground position information
    d. target data

17. The voltage that is fed to the computer representing range is obtained from the
    a. stabilizing system
    b. radar
    c. release point data computing system
    d. tracking control unit

18. The range measured by the radar is ALWAYS
    a. horizontal ground range between the aircraft and the target
    b. horizontal ground range between the aircraft and the aim point
    c. slant range from aircraft to the aim point
    d. slant range from aircraft to the target

19. Measured values of roll, pitch, and relative bearing are fed to the optical and radar systems from
    a. the stabilization system
    b. the pilot changing course
    c. the introduction of winds into the system
    d. changing the ballistic data inputs

20. Position deviation indications are computed by the
    a. radar
    b. autopilot
    c. release point data computing system
    d. gyro

21. During the operation of the ACS Aero 18, LABS equipment, when the pilot depresses the PICKLE switch, he
    a. recycles the equipment to start a new run
    b. starts the timed run
    c. drops his bomb
    d. cages the gyro

22. When using the over-the-shoulder bombing technique, the attack may be started when over the
    a. offset aim point
    b. initial point
    c. target
    d. initial point or the target

CHAPTER 9

ELECTRICAL EQUIPMENT

As the name of this chapter conveys, it is concerned with the electrical components serviced by the Aviation Fire Control Technicians. This chapter is dependent upon *Basic Electricity*, NavPers 10086, for the electrical principles applicable to these components. In the first section of this chapter, we shall consider the characteristics, types, uses, and tests of the more common electrical components which have not been covered in the basic course. The second section will be utilized in presenting techniques used in the electrical maintenance of aviation fire control equipment.

CHARACTERISTICS, TYPES, USES, AND TESTING

Solenoids

CHARACTERISTICS.—A solenoid is an electromagnet formed by a conductor wound in a series of loops in the shape of a helix (spiral). Inserted within this spiral or coil is a soft-iron core and a movable plunger. The soft-iron core is pinned or held in position and therefore is not movable. The movable plunger (also soft iron) is held away from the core by a spring in the deenergized position as shown in figure 9–1.

When current flows through the conductor, a magnetic field is produced. This field acts in every respect like a bar magnet having both a north and south pole. The total magnetic flux density produced is the result of the generated magnetomotive force and the permeability of the medium through which the magnetic field passes.

In much the same way that electromotive force is responsible for current in a circuit, magnetomotive force is responsible

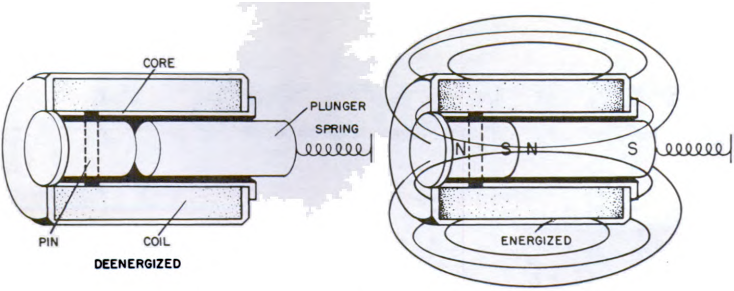


Figure 9–1.—Solenoid action.

for external magnetic effects. The magnetomotive force (m. m. f.) which produces the magnetic flux in a solenoid is the product of the number of turns of wire and the current through the coil. If the current is expressed in amperes, the magnetomotive force is expressed in AMPERE TURNS. From this it can be seen that a prescribed magnetomotive force can be produced by using either a few turns of large wire (high current) or many of small wire (low current).

The soft iron core will also influence the strength of the magnetic flux produced by the coil. The strength of the field is greatly increased by the use of a soft-iron core due to the greater permeability of iron in respect to air. Consequently, by using an iron core a greater flux can be produced for a given number of ampere turns.

The magnetic flux produced by the coil will result in establishing north and south poles in both the core and the plunger. These poles have such a relationship that the plunger is attracted along the lines of force to a position of equlibrium when the plunger is at the center of the coil. As shown in figure 9–1, the deenergized position of the plunger is partially out of the coil due to the action of the spring. When voltage is applied, the current through the coil produces a magnetic field which draws the plunger within the coil, thereby resulting in mechanical motion. When the coil is deenergized, the plunger returns to its normal position by the spring action. It is interesting to note that the effective strength of the magnetic field on the plunger varies with the distance between the two. For short distances the strength of the field is strong and as distances increase the strength drops off quite rapidly.

Uses.—Solenoids are used for electrically operating hydraulic valve actuators, radar waveguide shutters, carbon pile voltage regulators, power relays, and mechanical clutches. They are also used for electrically firing guns and for a great many other purposes where only small movements are required. One of the distinct advantages in the use of solenoids is that a mechanical movement can be accomplished at a considerable distance from the control. The only link necessary between the control and the solenoids is the electrical wiring for the coil current. This can result in considerable saving in space and weight—two vital elements in aircraft. Since solenoids are used in aviation fire control equipment and are subject to failure, the AQ should be able to test and maintain them.

Maintenance.—The first step to be taken in checking an improperly operating solenoid is a good visual inspection. The connections should be checked for poor soldering. loose connections, or broken wires. The plunger should be checked for binding, mechanical failure, and improper alinement adjustment. The mechanism that the solenoid is to actuate should also be checked for proper operation.

The second step would be to check the energizing voltage by use of a voltmeter. If this voltage is too low, the result would be less current flowing through the coil and thereby a weak magnetic field. A weak magnetic field can result in slow, ineffective operation. It could also possibly result in chatter or inoperation. If the energizing voltage is too high, it will in all probability damage the solenoid by either overheating or arcing. In either case the voltage should be reset to the proper value so that further damage or failure will not result. The solenoid should then be checked for opens, shorts, and increased or decreased resistance.

If the solenoid winding is open, the current cannot flow through the coil and consequently results in the loss of the magnetic field. A short will mean fewer turns and higher current. However, the short will normally have some resistance (poor contact) and resulting weaker magnetic field.

A high resistance coil will reduce coil current and also result in a weak magnetic field. To check for opens, shorts, and correct resistance, an ohmmeter should be used. Another check possible with the ohmmeter is to determine if the coil winding is shorted to ground. If the coil is open, shorted, or has appreciatively increased in resistance, the solenoid should be replaced.

Fuses and Circuit Breakers

The electrical system of an aircraft is protected from failure and damage by fuses, circuit breakers, other protective devices, and sectionalization. Because the AQ is responsible for the protective devices employed in the aviation fire control equipment, he should understand the operation of these devices. The two most common protective devices used in aircraft are fuses and circuit breakers.

It is instructive to consider for a moment the term sectionalization. Sectionalization is the arrangement of electric components and devices to provide alternate paths of power to the components. Thus, if an electric circuit to a turret, for example, is broken by gunfire, the turret receives power from an alternate path. Sectionalization increases the number of circuit paths and junctions. Current limiters (copper fuses), fuses, or breakers are placed in the circuit at all junctions. These limiters are most effective because of their ability to sustain overloads. The current limiter is shown in figure 9–2.

CHARACTERISTICS AND USES.—The most common overcurrent device is the fuse. A FUSE is merely a short length of wire or metal or metal ribbon within a suitable enclosed container. This ribbon (or link) is usually made of an alloy that has a low melting point and of a size which will carry a given amperage indefinitely. A larger current causes the metal to heat and melt, opening the circuit to be protected. Most fuses are made of an alloy of tin and bismuth, but copper, aluminum, German silver, or iron alloys have been used. A fuse is ALWAYS placed in series with a circuit so that it opens the circuit automatically.

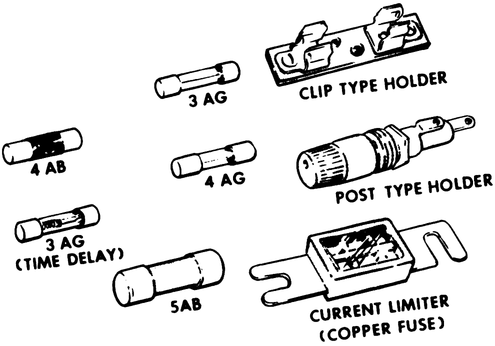


Figure 9–2.—Types of aircraft uses and fuse holders.

The standard type fuse used in naval aircraft is the cartridge fuse. The more common types of fuses and fuse holders are shown in figure 9–2. The current capacity of each fuse is marked on the side of one of the ferrules (caps).

The cartridge fuses are made in various physical sizes. The size is indicated by the AG or AB number. The AG indicates a glass body and the AB a bakelite body. Listed below are the dimensions of the standard AG or AB numbers:

1 AG or AB is $\frac{5}{8}$ inches long and $\frac{1}{4}$ inch in diameter.
3 AG or AB is $1\frac{1}{4}$ inches long and $\frac{1}{4}$ inch in diameter.
4 AG or AB is $1\frac{1}{4}$ inches long and $\frac{9}{32}$ inch in diameter.
5 AG or AB is $1\frac{1}{2}$ inches long and $\frac{13}{32}$ inch in diameter.

These fuses are rated at 80 percent of the current that they will carry indefinitely. The INSTANTANEOUS fuse must be able to carry a current 10 percent greater and must open the circuit at a current 25 percent greater than the fuse rating.

Another consideration in the use of a fuse is the voltage rating. This rating refers to the maximum voltage possible in the circuit in which the fuse is to be used. It is the voltage that the fuse construction can safely handle without arcing. If a fuse opens, the entire applied voltage of the circuit will appear across the fuse. Therefore, the voltage rating of the fuse should be higher than the maximum circuit voltage.

Some fuses are designed to have a time delay for overloads. This feature is necessary to keep short time surges, such as high starting current for motors, from melting (blowing) the fuse. This time delay permits momentary high current without injuring the fuse, while continuous excessive current results in a rupture of the fuse. The time delay can be accomplished by making the fuse link of heavy construction except in one or two short portions of its length. This allows the heat to be drawn away from the small high resistance portions thereby delaying the melting time. Fuses used in aviation are not the reusable or repairable type. They must be replaced with a new fuse after the defect in the equipment has been repaired.

In just about every naval aircraft today, a comparatively small device plays the role of guardian over the network of wires and cables making up the electrical system. This key to safety is the CIRCUIT BREAKER. The circuit breaker is designed to open the circuit under short-circuited or overload conditions without injury to itself. Thus, it performs the same function as the fuse, but has the advantage that it is capable of being reset and used again. As the fuse, the circuit breaker is also rated in amperes and voltage.

While there are three basic types of circuit breakers (thermal, magnetic, and thermomagnetic), our main considerations will be directed toward the thermal type because the thermal is at present more universally used. For this discussion, we shall divide circuit breakers into three categories—the pushbutton reset, the toggle type, and the automatic reset type (sometimes called a circuit protector).

The PUSHBUTTON reset type consists of a bimetallic, thermally (heat) actuated, spring-loaded device which closes the two electrical contacts when set. This is shown in figure 9–3. An excessive current through the device causes an uneven expansion of the bimetallic mechanism which releases a trigger escapement. This release permits the spring loading to rapidly separate the movable and stationary contact members.

A visual indication of the automatic opening is provided by causing the pushbutton to move to an easily noticed

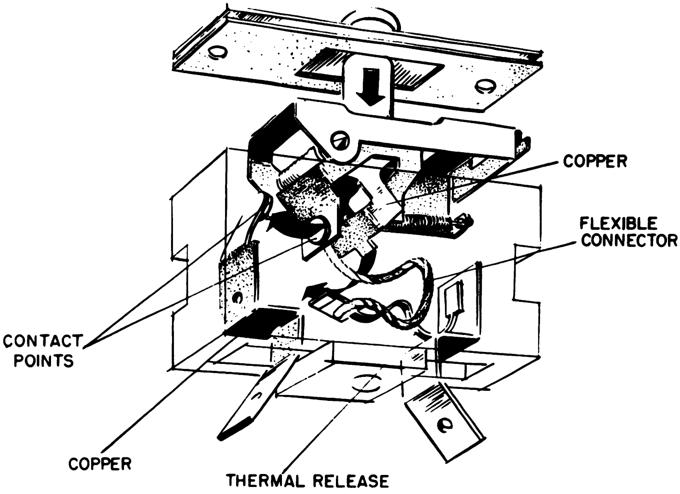


Figure 9–3.—Thermal circuit breaker.

"tripped" position. In this position the button is fully extended and the luminescent ring plus the inner red section of the button is showing. The latest type of pushbutton breakers have a pullout feature which permits manual opening of the circuit, but this type should NOT ordinarily be used as a switch.

In place of the pushbutton actuator, a toggle lever is used on another type of circuit breaker. It operates as the previously discussed breaker with the exception that the tripped position is indicated by the position of the toggle lever being in the OFF position. This type of circuit breaker has the apparent advantage of use as a switch.

Manual resetting of the circuit breaker may be accomplished means of the actuator (either pushbutton or toggle lever) whenever the bimetallic thermal element cools sufficiently for the trigger to engage its latching mechanism. Related to resetting is another classification for circuit breakers; namely, trip-free and non-trip-free. The non-trip-free circuit breakers are those which can be maintained closed by the operator's action while a tripping condition exists. The trip-free classes are those in which manual overriding of the trip mechanism is impossible. In recent years the trip-free type has been specified in new installations.

Another type of circuit breaker is the switch toggle variety based on MAGNETIC instead of thermal operation. This type can be made to open almost instantly when MORE than the rated current flows in the circuit. To accomplish this, an electromagnet is placed in series with the contacts and the contacts are mounted on an armature. When an excess current flows through the device, the armature will be pulled toward the electromagnet, opening the contacts and thereby the circuit. The armature is then latched in the off or tripped position. To reset the circuit breaker, the armature is unlatched and returned to the normal position.

The AUTOMATIC RESET type circuit breaker is similar to the bimetallic or thermal circuit breaker. It differs in that there is no actuator and that the bimetallic strip is a snap-acting disk which bridges two electrical contacts. When the strip is heated, instead of releasing a tripper escapement, the disk snaps in the reverse position thereby opening the contacts and the circuit. (See fig. 9–4.) After a short time, when the strip has cooled sufficiently, the strip will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

MAINTENANCE.—The maintenance of fuses is a very simple operation. Since the fuse is usually designed with a glass body, a visual inspection will normally disclose an open fuse. If there is any doubt as to the condition, a continuity test will readily indicate an open or closed fuse. If the fuse is defective, it must be replaced.

Occasionally the fuse holders will become defective. Here, once again, the maintenance required is a visual inspection followed by a continuity test. Broken wires, cold solder joints, and broken or missing parts can usually be detected by a visual inspection. A continuity test will indicate the condition of the connection and if any opens exist. If the holder is found to be defective, it should be replaced.

Circuit breaker maintenance presents a little more difficulty due to the possibility of a change in current capacity.

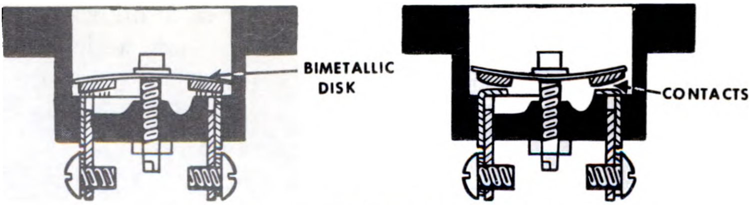


Figure 9–4.—Automatic reset circuit breaker.

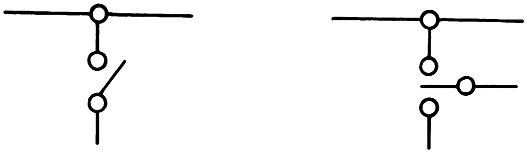
This change may result from usage over a period of time and is difficult to detect. If the current carrying capacity increases, the circuit protection value will be reduced. If the current carrying capacity decreases, the circuit breaker will open with less than rated current. Normally, under this condition the circuit breaker is the last component suspected because its opening usually indicates a circuit failure.

The usual maintenance of breakers involves a visual inspection of the terminals and resistance checks. These tests will indicate an open, shorted, or grounded condition. The calibration of the breaker is usually checked by comparison with a replacement. If a breaker malfunctions or appears to be operating improperly, it should be immediately removed and replaced by a new device of the same type and rating.

Switches

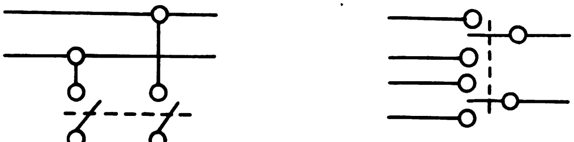
The one component that is common to all types and classes of fire control equipment is the switch. Switches are used for many different jobs, such as applying power, selecting armament, selecting radar or fixed ranging, applying power to sight lamps, releasing or firing ordnance stores, operating relays, and many other jobs. A switch may be described as a device used in an electrical circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Because it is placed in series, all the circuit current will pass through the switch. Because it opens the circuit, the applied voltage will appear across the switch in the open circuit position. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches normally utilize a snap action.

Many types and classifications of switches have been developed. A common designation is by the NUMBER OF POLES, THROWS, and POSITIONS they have. The number of poles indicates the number of blades or movable contacts of the switch. The throw of a switch signifies the number of circuits each blade or movable contact can complete through the switch. The number of positions indicates the number of places at which the operating device (toggle, plunger, etc.) will come to rest. Figure 9–5 presents the schematic diagrams of some often encountered switches.



SINGLE - POLE, SINGLE - THROW (SP ST)

SINGLE-POLE, DOUBLE-THROW (SP DT)



DOUBLE-POLE, SINGLE -THROW (DP ST)

DOUBLE-POLE, DOUBLE-THROW (DP DT)

Figure 9–5.—Commonly used switches.

An example of the switch position designation is a toggle switch which comes to rest at either of two positions, opening the circuit in one position and completing it in another. This is called a TWO-POSITION switch. A toggle switch which is spring loaded to the OFF position and must be held in the ON position to complete the circuit is called a SINGLE-POSITION switch. If the toggle switch will come to rest at any of three positions, it is called a THREE-POSITION switch.

Another means of classifying switches is the method of actuation; that is, toggle, pushbutton, sensitive, and rotary types. Further classification can be accomplished by a description of switch action such as ON-OFF, Momentary ON-OFF, ON-Momentary OFF, etc.

The most common type of aircraft switch is the toggle. Toggle switches have their moving parts enclosed. A double pole, double throw ON-OFF-ON toggle switch is shown in figure 9–6. These switches have many uses such as applying power; selecting guns or rocket operation; selecting MANUAL, OFF, or AUTOMATIC RADAR search operation; etc.

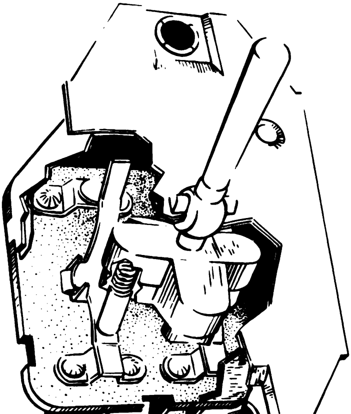


Figure 9–6.—Toggle switch.

Pushbutton switches have one stationary contact and one movable contact. The movable contact is attached to the pushbutton by an insulator. This switch is usually spring loaded and is of the momentary contact type. These switches have many uses, such as indicator light check, accept or reject target, and MOD RESET switches. Occasionally you will find the push-on and push-off type of switch, but these are not common in naval aviation.

Sensitive switches are small, short-travel, snap-action switches. They are manufactured as (1) normally open, (2) normally closed, and (3) double throw. The latter has no OFF position. The term Micro switch, although frequently used in referring to all switches of this type, is a trade name for the switches made by the Micro Switch Division of Minneapolis Honeywell Regulator Co.

Sensitive switches are usually of the pushbutton variety and are often used as limit switches. These switches usually depend upon one or more springs for their snap action. For example, the heart of the Micro switch is a beryllium copper spring, heat treated for long life and unfailing action. The simplicity of the one-piece spring contributes to the long life and dependability of this switch. The Micro switch is shown in figure 9–7.

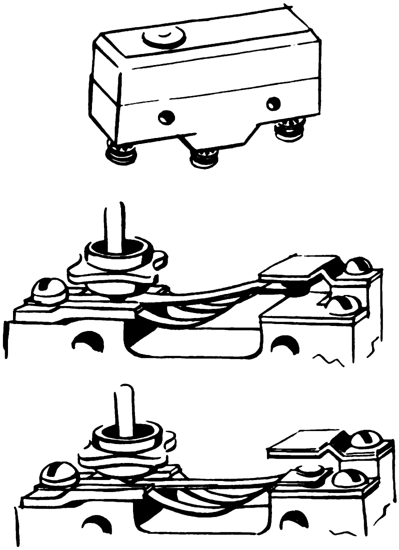


Figure 9–7.—Micro switch.

Rotary selector switches take the place of several switches. As the knob of a rotary selector switch is rotated, it opens one circuit and closes another. This can be seen from an examination of figure 9–8. Some rotary switches have several layers or wafers. By adding wafers, the switch can

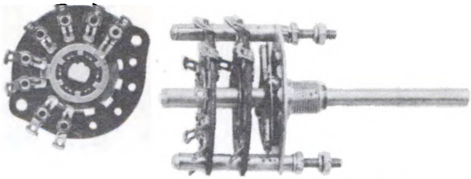


Figure 9–8.—Rotary selector switch.

be made to operate as a large number of switches. Rotary switches find application in fire control equipment as a reticle image selector, mode selector on radars, antenna scan width selector, and many others.

MAINTENANCE.—While the switch itself is relatively simple to check, it sometimes offers difficulty in maintenance because of its location in inaccessible places. After a visual inspection of the connections and the switch, a continuity test will indicate any malfunctions. When the switch mechanism is found to be defective, it normally is not repairable and therefore should be replaced.

When enclosed switches are used, failure to seal properly around cable openings causes most difficulty. Altitude changes permit "breathing" of moist air into enclosures with improperly sealed cable openings, and the moisture in the air may condense within the switch enclosure. The condensation can short across the switch terminals and can corrode the switch actuators in a manner that may make them inoperative. This difficulty can be corrected by careful sealing of openings or by using hermetically sealed switches. Hermetically sealed switches will also prevent dust and dirt from reaching the contacts and thereby causing high resistance and open circuits.

Some switches are damaged during installation, particularly those with plastic housings. Proper care in installing or replacing plastic enclosed switches will eliminate this.

Some switches depend upon pressure for their operation. These switches have adjustments so that they will operate at the correct time or pressure. In many cases if the adjustments are not accurate, damage can result. To the Aviation

Fire Control Technician, the importance of accuracy cannot be overstressed. As an AQ, you will find that a careful study of the circuit operation plus care and accuracy while making adjustments will be your two main assets while working on switches.

Relays

Relays play a prominent role in aviation fire control. They are used to connect power to motors, lights, heaters, sights, and radar equipment. They are also used to change circuit connections thereby permitting different modes of operation.

Along with their associated manual switches and circuit breakers, relays are used to start, stop, and regulate the current in the complex armament control systems used in modern naval aircraft. Because of the wide application of these devices, it is important that you become as familiar as possible with the function of these devices and their applications.

Relays may be classified according to their use as control relays or power relays, known as relays and contactors. As AQ's, you will be more associated with control relays. The power relays are the work-horses of the aircraft's electrical system. As such, they control the heavy power circuits.

The function of a control relay is to take a relatively small amount of electrical power and use it either to signal or to control a large amount of power. Where multipole relays are used, several circuits may be controlled simultaneously.

The control relays may act in somewhat the same capacity as a vacuum tube amplifier in an electric circuit. While the vacuum tube is ordinarily used to amplify voltage, the relay usually amplifies current or power. The use of relays saves space and weight in the aircraft by permitting the use of small switches at remote control stations. These switches permit the operator to control large amounts of current at other locations in the equipment, and the heavy power cables need to be run only to the point of use. Only lightweight control wires are connected to the control switches. Safety is also an important factor in using relays, since high power circuits can be switched remotely without danger to the operator.

Control relays, as their name implies, are frequently used in the control of other relays, although the small control relays find many other uses. With them, electron tube plate currents can control larger currents necessary to operate electrical devices. They find frequent use in automatic relaying circuits, where a small electric signal sets off a chain reaction of successively acting relays performing various functions. Control relays can also be used in so-called "lockout" action to prevent certain functions, such as gunfiring, from occurring at the same time as other functions. Various electrical operations in the equipment which must not occur simultaneously can be "interlocked" by control relays. Another important function of control relays in aircraft equipment is for "sensing." Control relays are used for sensing undervoltage and overvoltage, reversal of current, and excessive currents.

Another possible classification of relays is open, semisealed, and sealed. Semisealed relays have protective covers and are gasketed against entrance of salt, dust, and foreign material into the contact or mechanism area. These relays are still considered satisfactory for certain applications in present day aircraft.

For other applications in today's high-altitude, high-speed aircraft, however, it is necessary to go beyond the protection offered by the open type and the semisealed relays. When such relays are used, quick changes in altitude, humidity, and temperature can cause condensation of water vapor within enclosed volumes. Subsequent low temperature will then freeze the moisture on the contactor with a resultant inability to carry electric current. It is interesting to note that only open relays found in aircraft fire control equipment are within components such as radar modulators which are sealed with increased pressure within the unit, and therefore are not subject to "breathing" effects.

Hermetically sealed relays were developed to answer the demands of most modern aircraft equipment. A true hermetic seal is generally considered one that is metal to metal or glass to metal. Plastic or plastic rubber type gasketed seals are generally not considered true hermetic seals. However, both semisealed and hermetically sealed relays are used. There are applications where a gasket type sealed relay may be adequate, but the true hermetically sealed type is generally considered to be more permanent. Besides being independent of altitude changes, the hermetically sealed relay also has the advantage of being tamperproof.

In general, a relay is divided into three basic components, the magnet and associated coil, the contacts, and the mounting and can (if sealed). A manual switch, limit switch, or other small control device starts and stops the flow of current to the magnet coil. The flow of electric current through the coil creates a strong magnetic field around and within the coil. This magnetic field is put to work by operating a clapper or plunger which completes the magnetic circuit. The contacts which control the large current are fastened mechanically to this movable clapper or plunger, so that they make contact with nonmovable contacts to complete the circuit. Figure 9–9 (A) shows a basic single coil clapper type relay. The dashed lines indicate the magnetic lines of flux.

The second basic type of relay is the rotary shown in figure 9–9 (B). Although this type of construction is relatively new and not as common as the clapper type, the rotary type has greater vibration and shock resistance than the others. The disadvantage is that they are somewhat sluggish and require higher operating power for many purposes. The rotary relay operates on the principle of an electric motor, but through only a small arc. The problem of hanging contacts on such a mechanism is a difficult one, and therefore the use of these devices is limited to application where high shock warrants the larger size and weight. When used with standard wafer switch assemblies, this type of relay provides a means for assembling a switching device of any degree of complexity.

Occasionally you will encounter relays operating from an

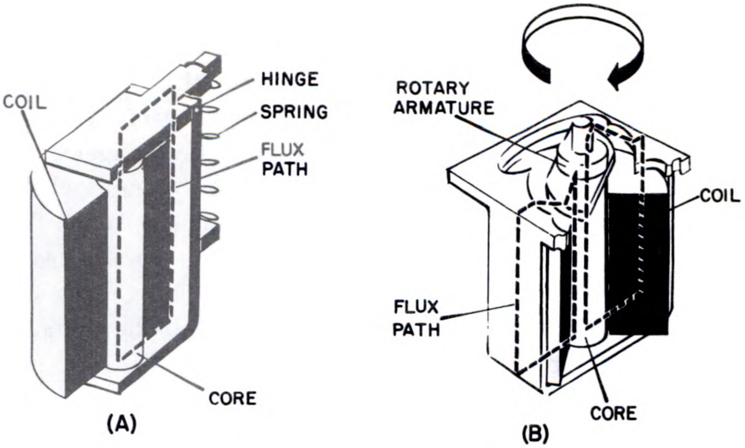


Figure 9–9.—Basic types of relays.

a-c supply. These a-c relays depend upon the same fundamental principles as the d-c relay; that is, magnetic fields. When a. c. is applied to an electromagnet, the current will pass through zero twice every cycle. Since the pull on the armature is proportional to the current through the electromagnet, the armature will open every time the current nears zero, causing chatter. To remedy this, shading coils (or, as sometimes called, shaded poles) are used.

A shading coil consists of a copper band or stamping which is short-circuited and embedded around PART of the electromagnet pole face. By being placed around part of the pole face, it acts as a shorted transformer secondary. The current in the main coil lags the applied voltage by approximately 90 degrees, and the flux is in phase with the current. The voltage of the shading coil is induced voltage and lags the current in the main coil by 90 degrees. Since the shading coil acts like a shorted secondary (resistive), the current in the shading coil is in phase with the induced voltage. Therefore, the magnetic field of the shading coil lags the magnetic field of the main coil by 90 degrees. This means that flux will exist in the electromagnet even when the main coil current becomes zero. Thus, chattering is prevented.

The arrangement of relay contacts are found in many different forms. Usually the number and sequence of switching operations to be performed dictates the contact arrangement. Figure 9–10 shows the basic relay contact groups which form the basis for the various arrangements. Related to these considerations is the term "pileup" which refers to the method of operating the contacts. When the armature closes, the first set of contacts are forced against a spacer which forces the second set of contacts against another spacer, and so on. The result is that all the contacts close by "piling up."

It is often desirable to introduce time delays by use of

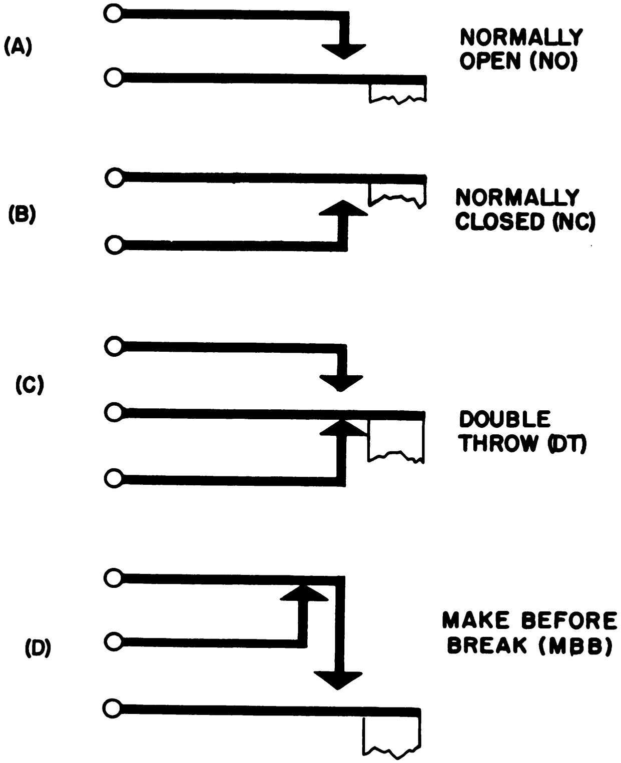


Figure 9–10.—Basic relay contact groups.

relays. One method is to use a thermal relay for a time delay. The operation of this type of relay is very similar to the thermal circuit breaker with the exception that it closes the circuit rather than open it, when heated. Due to the simple mechanism, it can be made very small and hermetically sealed. making it ideal for use in aircraft. Because the thermal relay is activated by heat, it can be used on either a. c. or d. c.

Another type of time delay relay, which is often found in radars, is the motor driven clock type. This relay is used to prevent the application of plate voltage until the tube filaments have had sufficient time to warm to operating temperature. This safety measure increases tube life considerably.

MAINTENANCE.—The relay is one of the most dependable electromechanical devices in use, but like any other mechanical or electrical device in aircraft equipment, relays occasionally wear out or become inoperative for one reason or another. Should relay inspection determine that a relay has exceeded its safe life, the relay should be removed immediately and replaced with another of the same type. Care should be exercised in obtaining the same type replacement because relays are rated in both voltage and amperage.

As guides for spotting potential relay trouble during preventive maintenance, the following are suggested. Check for charred or burned insulation on the relay. Check for darkened or charred terminal leads coming from the relay. Both of these indicate overheating. If there is even a slight indication that the relay has overheated, it should be replaced with a new relay of the same type. An occasional cause of relay trouble is not the fault of the relay at all, but is due to overheating caused by the power terminal connectors not being tight enough. This should always be checked on preventive maintenance.

It is not recommended that covers be removed from semisealed relays in the field. Removal of a cover in the field, although it might give useful information to a trained eye, may result in entry of dust or other foreign material which may cause contact discontinuity. What is even more serious, removal of the cover may result in loss of or damage to the cover gasket. This will increase the explosion hazard. One of the prime advantages of hermetically healed relays is that they cannot be taken apart.

Rheostats and Potentiometers

Rheostats and potentiometers are variable resistors which are used in aviation fire control equipment. They are used for such diverse functions as operating controls, lighting controls, alinement adjustment, computing, and tracking. Essentially, the difference between the two is their USE.

A rheostat is a variable resistor which is used to adjust the CURRENT in a circuit or a portion of a circuit in which it is connected. This is done without opening the circuit. Generally, a rheostat has two terminals; one terminal is connected to one end of the resistance element, and the other terminal to the slider arm contact. (See fig. 9–11 (A).) However, it should be noted that rheostats occasionally have three terminals.

As shown in figure 9–11 (A), the resistance element is circular in shape and is made of resistance wire wound around an insulating form usually made of a ceramic material. Ceramic is used to withstand the heat developed in the resistance wire. By rotating the wiper contact toward the end contact attached to the resistance element, the resistance between the end terminal and the wiper contact terminal is decreased. A reversal of the direction of movement will, of course, increase the resistance. Note that the wiper contact cannot vary through 360 degrees due to limit stops.

Because a decrease in resistance of a circuit will increase the current, there is the danger of overheating a rheostat when only a few turns of resistance wire are in use. Therefore, rheostats are rated by their maximum resistance and the maximum permissible current through ONE turn of the resistance wire. The current rating can be increased by using different sizes of resistance wire during winding. In this

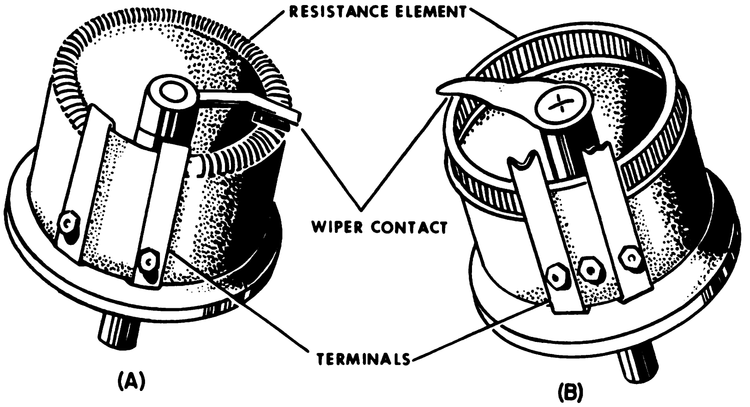


Figure 9–11.—Rheostat and a potentiometer.

type, the heaviest wire is employed when only a small part of the resistance wire is in use. Two examples of the use of rheostats in fire control equipment are (1) varying the current in the field winding of a gyro, and (2) adjusting the brightness of panel lights.

Like the rheostat, the potentiometer is also a variable resistor. However, a potentiometer is a control device used to vary the amount of voltage applied to an electrical device. Popularly the term potentiometer refers to any adjustable resistor having three terminals, two of which are connected to the ends of the resistance element and the third to the wiper contact. (See fig. 9–11 (B) and fig. 9–12.) Examples of the use of wire wound potentiometers in fire control equipment are (1) the ranging throttle grip, and (2) antenna elevation and horizontal position potentiometers.

The resistance element of the potentiometer is always wire wound in the precision types. The element is constructed by winding resistance wire around a flat rectangular piece. The rectangular form is called a card or mandrel and is made of plastic, fiber glass, or other insulating material. The resistance wire is usually made of a nickel-copper or nichrome alloy. The accuracy of the potentiometer depends upon the accuracy of the card dimensions and winding. As shown in figure 9–11 (B), the card is bent into a circular form to facilitate the use of a rotary wiper contact. The accuracy and life of a potentiometer depends to a great extent upon the movable contact. These wipers are usually made of a softer metal than the resistance wire in order to reduce the wear upon the wire.

As the wiper is moved through its arc, the resistance between the end terminals and wiper terminal will vary. As the resistance between one end and the wiper increases, the resistance between the other end and wiper will decrease. Notice how the potentiometer (often called "pot") in figure 9–12 is used as a means of obtaining a variable voltage from a fixed voltage source for an electrical device. The voltage applied across the device is equal to the voltage from B to C because the load is connected in parallel. When the slider arm is moved to point C, the voltage across the load is zero. The potentiometer makes it possible to apply any voltage within the range between zero and full voltage across the load.

Let us now trace the current in the circuit. The current flows from the battery and divides into two parts. One part flows through the lower portion of the potentiometer, and the other part flows through the device. Both parts combine and flow through the upper portion, B to A, of the potentiometer back to the battery. From this it is apparent that the potentiometer must withstand the current drawn by the load as well as the current it draws itself.

Another observation from figure 9–12 is that the useful work is done by the current through the load. The energy in the current drawn by the potentiometer is dissipated in the form of heat. It is, therefore, advisable to keep this wasted current as small as possible by making the resistance of the potentiometer as large as is practicable. For this and other reasons, the resistance of the potentiometer in most applications is several times the resistance of the load.

All potentiometers do not have a straight-line (or linear) relationship between the degree of control (amount of knob turning) and the resulting output. In fire control equipment applications, potentiometers are often used for other

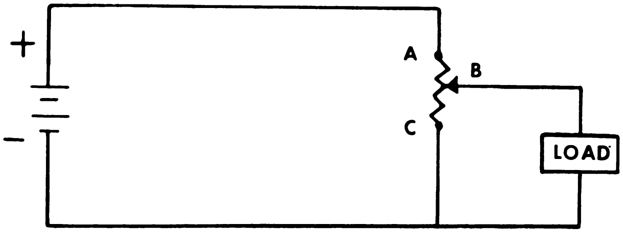


Figure 9–12.—Varying voltage with a potentiometer.

than linear relationships. Consider for a moment that the potentiometer in figure 9–12 has an even distribution of resistance across its entire length. It would then be classed as a LINEAR control. If it had more resistance per unit length at one end than at the other, it would be classed as a tapered control. As an example, the travel through one-half the arc of a linear control results in one-half of the total resistance between either end and the slider contact, while the travel through one-half the arc of a TAPERED control may result in one-tenth (or any fraction) of the total resistance between one end and the slider.

There also exists a need for obtaining voltages proportional to other nonlinear functions, such as sine and cosine functions in the solution of the fire control problem. This need has been satisfied by shaping a potentiometer card like a sine curve (as shown in fig. 9–13) and rotating the contact linearly. The card must be accurately shaped to provide the correct ratio of voltage to degrees of rotation. For example, since the sine of 30 degrees is 0.5, it is evident that the output voltage should be one-half the applied voltage when the contact has completed 30 degrees rotation. Sometimes the shape of the card has to vary from the true sine curve in order to compensate for the thickness of the card and obtain the proper ratio.

A potentiometer can also be made to give cosine functions. The cosine card has exactly the same shape as the sine card except that the contact taps off a maximum value of applied voltage at 0 degrees and 0 volts at 90 degrees. The reason for this is that the cosine of 90 degrees is 0, and the cosine

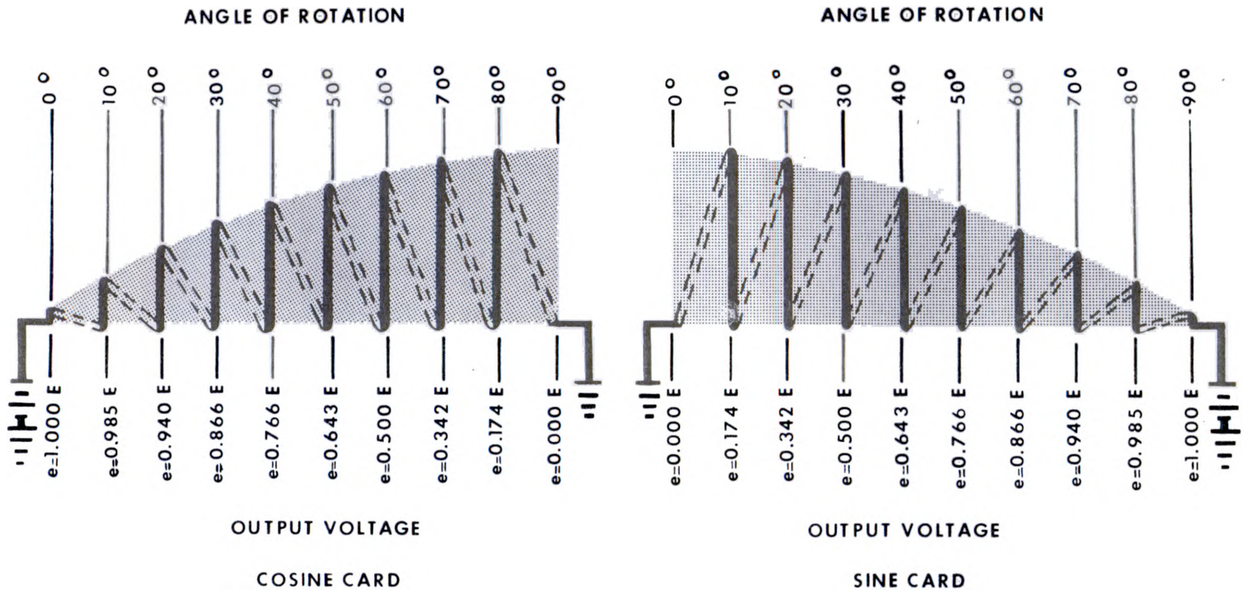


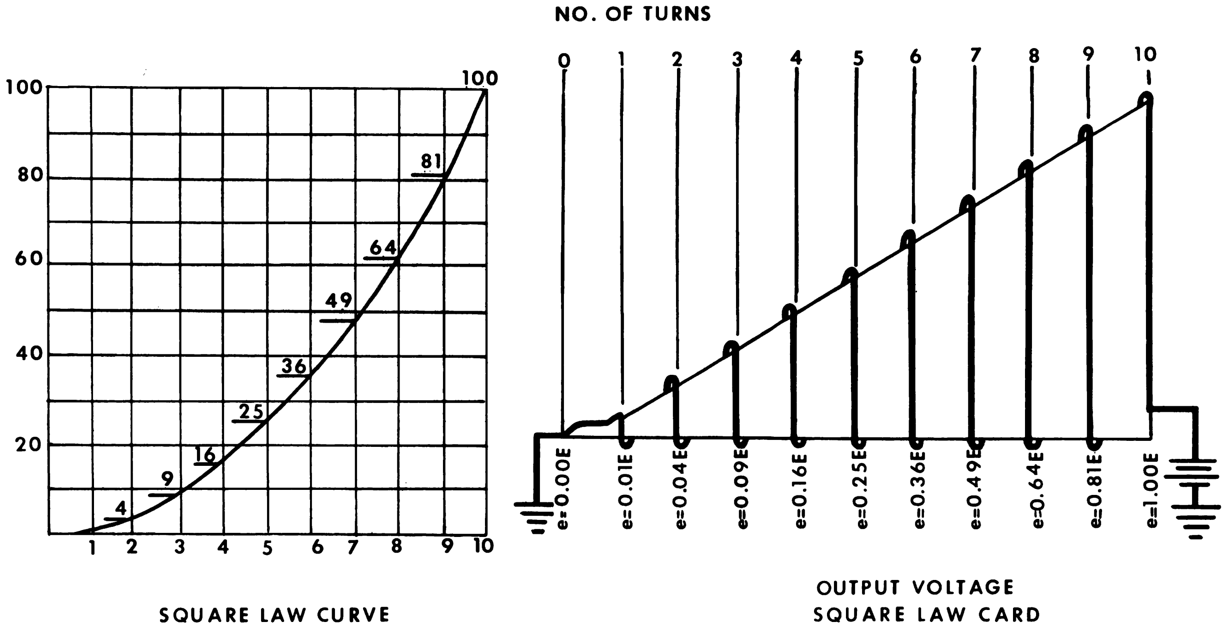
Figure 9–13.—Cosine and sine cards.

of 0 degrees is a maximum. With the type of cards shown in figure 9–13, it is possible to obtain voltages proportional to the sine or cosine of angles up to 90 degrees. Potentiometers have been constructed that will produce voltages proportional to the sine and cosine of any angle from 0 to 360 degrees.

The potentiometers just discussed use a linear movement of the contact and a nonlinear card. Another way to obtain a voltage proportional to these and other trigonometric functions is to use a linear card and a nonlinear movement of the contact.

Another nonlinear function that is used in the computation of the fire control problem is the square law function. The method of inserting this function is the square law potentiometer. Figure 9–14 shows the square law curve and square law card. Notice that the shape of the card varies from the shape of the curve to compensate for the thickness of the card and to obtain the desired ratio of voltage to degrees of rotation. As the previously discussed cards, this type is also bent in a circular form and the wiper makes contact with the base of the card shown in the figure. The square law card is so designed that as the contact wiper moves along the base, a voltage proportional to the square of numbers on the dial is obtained. Assume for example, that there are ten turns of wire on the card. For each turn on the card the output voltage increases as the square of the number of turns. If the output of the first turn is 1 volt, then the output of the second turn is 2^2, or 4 volts, the output of the third turn is 3^2, or 9 volts, and so on.

Our discussion up to this point has centered around the precision or wire wound potentiometers. Another very common type of potentiometers is the type that uses a resistance composition, usually carbon, for the resistive element. This type is used in low current circuits and when high accuracy is not a requirement. The main advantage of this type is that it is inexpensive. Carbon potentiometers are used for such purposes as receiver gain, intensity control, and low voltage adjustments.



SQUARE LAW CURVE

OUTPUT VOLTAGE
SQUARE LAW CARD

Figure 9–14.—Square law potentiometer card.

MAINTENANCE.—In both preventive and corrective maintenance, the first step to be undertaken is a thorough visual inspection. Such an inspection should reveal any improper soldering, loose connections, or broken leads. It will also disclose any overheating which results in charred, discolored, or blackened terminals, connectors, or leads. Another step in the maintenance of rheostats and potentiometers is to check, where possible, for binding or uneven motion of the wiper contact. A word of caution here; adjustments should never be needlessly changed.

Other checks of these variable resistors are tests for shorts, opens, and grounds. An ohmmeter should be used to measure the actual resistance between terminals when the device is suspected of erroneous operation. Resistance measurements while the device is still connected in the equipment will usually result in incorrect readings because of other components in parallel with the measured device. If the potentiometer or rheostat is found to be defective either electrically or mechanically, it should be replaced with another of the same AN type. The Bureau of Aeronautics does not recommend overhaul or repair of potentiometers.

Electrical Connectors and Cables

Because aviation fire control equipments are usually composed of many units, electrical connectors and cables, used in connecting these units, are also the maintenance responsibility of the AQ. As defined in chapter 6 of *Basic Electricity*, NavPers 10086, a cable is either a stranded conductor (single conductor cable), or a group of conductors insulated from each other (multiconductor cable). A wire is defined as a single, SOLID conductor. However, these definitions are not always strictly followed. In the aviation fire control literature, the words wire, wires, and cables are often used interchangeably.

Connectors are devices attached to the ends of cables and sets of wires to make them easier to install and remove. Connectors consist of two portions—the fixed portion, called the receptacle, and the movable portion, called plug. Plug assemblies may be of the straight type or the 90-degree type, while receptacle assemblies may be the wall-mounting, box-mounting, and integral-mounting types. Army-Navy specification numbers and letters identify the type, style, and arrangement of a connector.

CABLES.—All wires and cables installed in an aircraft are identified in accordance with specifications in the appropriate Military Specifications. The identifying symbols consist of a series of letters and numbers that signify circuit function, cable number, and cable segment. When a defective wire is replaced, splices are not permitted, and a complete new length of wire is installed. The wire must be of a type, length, and size to agree with specifications. Before the wire is installed, a band of cellulose type is wrapped around it near each of its terminals. The identifying number is typed on the tape, and a protective coating of shellac is applied. Some activities have a machine for marking wires. With these means of identification, a circuit can be traced and tested easily.

An example of wire identification coding is shown in figure 9–15. The UNIT NUMBER is used where two or more identical items of equipment are installed in the same aircraft and it is desired that both have the same wire identification number. The unit number is used to differentiate between the wires. The CIRCUIT FUNCTION letter is used to identify the function of the circuit. Y is the letter for armament systems.

The ARMAMENT SPECIAL SYSTEM NUMBER is used only with circuit function letter Y and is a further means of identification. The CIRCUIT DESIGNATION LETTER is a refinement of the circuit function and in this case signifies "turret." The wire number is used to differentiate between wires in a particular circuit. The wire segment letter is used to differentiate between conductor segments in a particular circuit. For a given wire run with a common wire number, the segments between terminals are lettered alphabetically from the power source.

Wire size number is used to identify the AN (copper) or AL (aluminum) size of the wire or cable. This is omitted

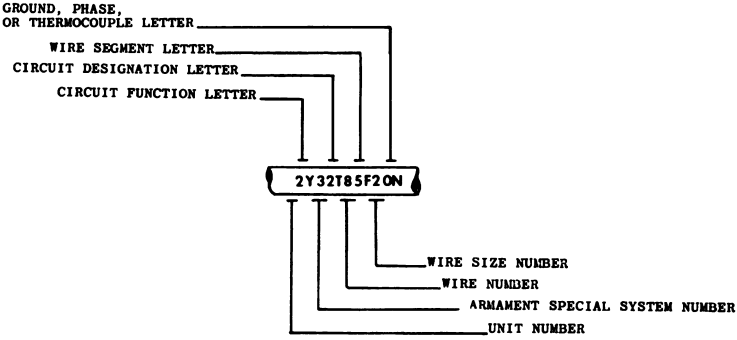

GROUND, PHASE, OR THERMOCOUPLE LETTER
WIRE SEGMENT LETTER
CIRCUIT DESIGNATION LETTER
CIRCUIT FUNCTION LETTER
2Y32T85F20N
WIRE SIZE NUMBER
WIRE NUMBER
ARMAMENT SPECIAL SYSTEM NUMBER
UNIT NUMBER

Figure 9–15.—Example of wire identification coding.

for coaxial cable, and a dash used for thermocouple wire. The final letter is used to indicate grounded (N), ungrounded (V), phase for a. c. (A, B, C), or material for thermocouple. Our example indicates the cable is grounded to the structure.

Although copper wire is used in a majority of aircraft installations, aluminum wire and cable is being utilized more extensively now than in years past. Large weight savings can be realized since aluminum wire weighs approximately half as much as equivalent copper wire with the same current carrying capacity. A detailed description of wire and cables is found in chapter 6 of *Basic Electricity.*

A Military Standard color code has also established a uniform wiring code for circuit identification. The standard colors to be used in chassis wiring for the purpose of circuit identification of the equipment is given in table 9–1.

Connectors.—While there are many types of electrical connectors used in aviation fire control equipment, our major concern in this discussion will center around the AN and coaxial cable connectors.

AN connectors are designed to provide a detachable means of connections between electrical circuits in aircraft. They are constructed to withstand the extreme operating conditions imposed by this service. Connectors used in these electrical circuits must make and hold electrical circuits securely

Table 9–1.—Standard color code for chassis wiring

Circuit	Color
Grounds, grounded elements, and returns	Black.
Heaters or filaments, offground	Brown.
Power supply B plus	Red.
Screen grids	Orange.
Cathodes	Yellow.
Control grids	Green.
Plates	Blue.
Power supply, minus	Violet (purple).
A–c power lines	Gray.
Miscellaneous, above or below ground returns, AVC, etc.	White.

and without undue voltage drop despite extreme vibration, rapid shifts in temperature, and vast altitude differences.

Basically, the plug and receptacle assemblies each consist of an aluminum shell containing an insulating insert which holds the current carrying contacts. This basic design permits a wide variation in shell type, design and size, contact layout, and insert style. An exploded view of a connector plug is shown in figure 9–16.

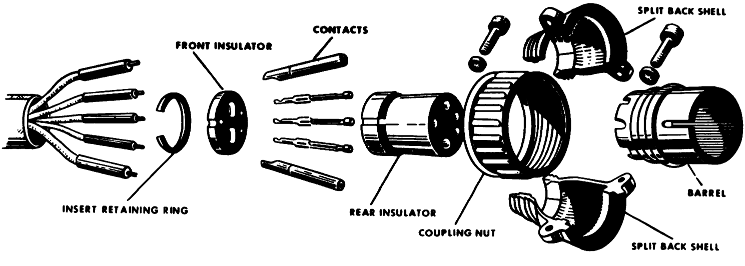


Figure 9–16.—AN connector plug.

There are eight shell types of AN connectors in use. Their number and nomenclature, which are mostly self-descriptive, are given in table 9–2. Integral is used in the sense that the plug or receptacle is an integral part of the equipment housing.

Table 9–2.—AN connectors

AN type	Nomenclature
AN 3100	Wall-mounting receptacles.
AN 3101	Cable-connecting receptacles.
AN 3102	Box-mounting receptacles.
AN 3106	Straight plugs.
AN 3107	Quick-disconnect plugs.
AN 3108	90-degree angle plugs.
AND 10066	Integral-mounting receptacles.
AND 10459	Integral-mounting plugs.

AN connector shells are also designed under five different classes for particular applications. The different classes are signified by a letter after the AN number. The letters and their meanings are: (A) solid shell, (B) split shell, (C) pressurized, (E) environment resistant, and (K) fireproof.

As pointed out previously, there is an AN numbering system for identifying the connectors. For example, a connector may be identified as consisting of an AN 3106B–22–12S plug with an AN 3102B–22–12P receptacle. These identifying letters and numbers stand for the following:

AN	AN nomenclature system
3106	Specification number for plug (straight plug)
3102	Specification number for receptacle (box receptacle)
B	Shell design (split type)
22	Size of the shell
12	Insert arrangement
P	Pin contacts
S	Socket contacts

Occasionally it may be necessary for you to fabricate a cable using AN connectors. The type of connector to be used will be specified in the maintenance manual for the particular equipment. The following is an outline of the procedure for fabricating; complete instructions are found in the *Handbook of Operation and Service Instructions—AN Electrical Connectors* (AN 03-5-90).

First prepare the cables by cutting to the correct length, stripping off the insulation, tinning the ends for soldering, and stamping the correct code on the conductors. If necessary, the connector should then be disassembled and placed in a vise or other holding device. Be careful not to damage the connector by overtightening. Don't forget to place the connecting ring over the cable prior to soldering connections. The connectors are then soldered to the contacts following a prearranged sequence. The recommended sequence is to start from the bottom connection and work from left to right moving up a row at a time. After soldering the connections, the shields, if used, are soldered to a common terminal on a ferrule. The cable is then laced and the connector reassembled and waterproofed if necessary.

COAXIAL CABLES AND CONNECTORS.—Flexible coaxial cables (sometimes called RF cables) are a special type of cable used for carrying video and RF signals, cathode-ray-tube sweep currents and voltages, trigger range marks, blanking pulses, and other signals of radar receivers, transmitters, and indicators. These cables are constructed with special considerations for shielding, impedance, capacitance, and attenuation. All of these factors are of importance in many circuits. Coaxial cables have neither induction nor radiation losses. These lines have low attenuation even at very high frequencies and are used as high as 3,000 mcps.

The name coaxial is derived from the construction, in that the inner and outer conductors have a common axis or coaxis. These cables consist of an inner conductor, a dielectric insulator, an outer conductor, and an outer covering. The inner conductor is usually made of copper, either plain, tinned, or silver coated. The dielectric insulation is usually polyethylene, although other materials are used. The outer conductor is made of a single or double braid of either plain, tinned, or silver coated copper. The outer covering is made of a synthetic resin (vinyl), teflon tape, or chloroprene.

This covering serves both as weatherproofing and protection from mechanical abuse.

Flexible coaxial cables are classified in four groups; namely, general purpose, high temperature, pulse, and special characteristics. The general-purpose cables consist of various sizes of cables as just described. The high temperature cable is basically the same but usually has a dielectric made of teflon, and the outer covering is made of teflon tape and fiber glass braid which enables it to withstand increased temperatures. Pulse cables have the ability to withstand high voltages because of conductor spacing and the type of dielectric used in their construction.

The special characteristics cables are made of various materials and sizes of inner conductor, outer conductor, dielectric, and outer covering. By varying these parts the capacitance, impedance, shielding, attenuation, voltage rating, and the ability to withstand weather and abuse are varied to fit the required qualities. With exception of the special characteristics type, these coaxial cables have an impedance in the order of 50 to 75 ohms. The impedance of the special characteristics type is often much higher. An example is the RG–65A/U which has a approximate impedance of 950 ohms and is used as a high impedance VIDEO cable. In replacing a coaxial cable, care should be exercised to use the correct replacement otherwise most of the advantages of coaxial cables are lost.

At frequencies near 3,000 mc., flexible coaxial cables have appreciable losses. At these frequencies rigid coaxial cables are used with air as the dielectric. The inner conductor is supported by ceramic or polystyrene beads.

Coaxial connectors may be divided into seven series (BNC, N, C, HN, LC, pulse, and twin). Each series consists of plugs, panel jacks, receptacles, straight and right angle adapters. The BNC series are small lightweight, quick-connect and quick-disconnect type used with small RF cables. The N series are the general-purpose screw-lock connectors. The C types are similar to the N series in that they are used with medium sized cables but have the quick-disconnect feature. HN types are high voltage connectors for use with medium sized cables while the LC series are large connectors. The pulse series are widely used in naval aircraft equipment. They are used with high voltage pulse cables, such as the modulator-to-transmitter pulse cable, in some airborne fire control radars. The twin series are used with cables that carry UHF frequencies and are sometimes called UHF connectors.

MAINTENANCE.—In the maintenance of cables and connectors, the first consideration is a thorough visual inspection. This check should reveal such defects as corrosion, chafing, loose connections, loose or broken strands, evidence of overheating, and battered or improperly mated connectors. Further checks can be made to ascertain if there are any open or shorted conductors in the cable. An ohmmeter is usually utilized to perform these checks.

In checking a suspected conductor for either an open or short, it may be necessary to supply a slight pressure to the conductor or to simulate the vibration occurring while airborne. Defective cables are NOT to be spliced; they are replaced. Shorts are often caused by moisture, foreign particles, or a defective solder connection at the plug terminals. Therefore, it is advisable to check the connectors carefully before replacing the cable.

In modern tactical aircraft, conduit is eliminated, wherever possible, to insure the wide separation of cables. Its elimination facilitates cable installation and maintenance and, in addition, saves weight. If cables are widely separated, the electrical system becomes less vulnerable to gunfire. In the individual routing of cables, the airplane is used to best advantage as an electrical shield for the cable. This shielding effect is used to reduce radio interference. In replacing a cable, take particular care to replace it in the exact position in which it was installed originally. Do not attempt to reduce the length of the cable by taking what may seem to be a logical shortcut.

The use of aluminum wire in aircraft has been well established and will probably increase because of its weight saving characteristics, its greater availability in time of war, and lower cost. Therefore, it is appropriate to note some of the unusual properties of aluminum and the precautions that must be observed in its use.

Aluminum is unusual in that it forms an electrically resistant oxide film on all of its surfaces; it has an inherent property known as "creep" which makes proper installation of a terminal extremely critical. Creep is the tendency of aluminum to actually flow away from the point where pressure is applied. Furthermore, aluminum is softer than copper, and reacts chemically when placed in direct contact with it.

The electrically resistant aluminum oxide film is always present and so must be either penetrated or removed in order to guarantee a satisfactory electrical connection. A compound called Penetrox A is used to remove this film. Initially, tin plated terminals and splices are supplied so that no oxide film will be present. If the terminals have become dirty due to storage or excessive handling, they should be cleaned by wiping with a soft cloth. NEVER use a wire brush or any abrasive method to clean a tinned aluminum surface.

One of the troublesome problems resulting from the use of aluminum wire is that caused by dissimliar metals. This problem occurs frequently when aluminum and copper are placed side by side. As soon as moisture accumulates between the two metals, an electrical differential exists which produces a "battery effect." This effect results in greater corrosion.

To reduce the undesirable effects caused by aluminum's softness, creep and oxide film forming the following techniques should be followed:

1. Select the proper size of wire and terminal. AL or ALUM are stamped on terminals and splices for use with aluminum wire.
2. Select the proper hand tool when crimping.
3. Handle the aluminum wire carefully and use the proper assembly procedure when preparing it for an electrical connection.

4. Thoroughly clean any terminals used.
5. Be careful NOT to notch or cut the wire.

If binding, seizing, or galling occurs when attaching either AN or coaxial plugs to their receptacles, special lubricants should be used after cleaning the metal surfaces. Such a lubricant is molybdenum disulfide. It can be applied by rubbing the powder on the metal threading or by painting a mixture of 10 percent molybdenum disulfide in alcohol on the surface and permitting it to dry.

MAINTENANCE TECHNIQUES

Soldering

A discussion of soldering is found in *Basic Electricity.* Let us now briefly review the highlights of that discussion and then consider some aspects peculiar to the AQ work.

Soldering is the uniting of two or more metals by means of a fusible alloy. There are two general classes of solder, hard and soft. The difference between the two are in composition, melting temperature and strength. Soft solder, an alloy of tin and lead, is used in electronic wiring. In naval airborne electronic equipment, a solder of 60 parts tin and 40 parts lead is preferred because it flows at a lower temperature and solidifies faster than standard tin-lead solders. Only rosin flux is to be used in soldering electrical connections.

Beside the soldering iron (copper) discussed in the basic text, soldering guns are often used by the AQ. The soldering gun consists of a stepdown transformer with the primary connected to 115-volt a. c., and soldering copper forming a loop across the secondary. The heat is generated by the secondary current and concentrated at the tip. This concentration of heat is due to the shape of the soldering end. It is a relatively safe device since it heats in a matter of seconds. Upon release of the trigger, the tip will cool in a corresponding short period of time.

Caution should be exercised in any soldering operation. One common misuse of the soldering iron is the improper removal of excess solder from the iron. The striking of the iron on a solid object to remove the excess solder should be avoided because this may damage the heater element. A practice occasionally used in the field is the whipping or swinging of the iron. This practice can prove to be very dangerous to nearby workers. Excess solder should be removed with a damp cloth. During the soldering operations and while the soldering iron is not actually in use, keep it in its holder to avoid a fire hazard. Contact with a hot iron or molten solder can cause serious and painful burns.

The correct procedure for soldering is given in *Basic Electricity*, therefore, it will not be covered here. Let us consider for a moment the end product—properly and improperly made soldered joints.

A good well-bonded connection is clean, shiny, smooth, and round. It shows the approximate outline of the wire and terminals. The wire and terminal are completely covered and the solder adheres firmly. The insulation is close but not in the hole or slot; it is approximately 1/8 inch from the terminal. It is not charred, burned, nicked, or covered with rosin. A film of rosin may remain on the joint and need not be removed unless the joint is in a high frequency circuit or unless fungusproofing is anticipated.

Soldered joints may be defective for a variety of reasons, such as the following. A COLD solder joint has a dull appearance and a crystallized texture. Because of the poor union between the wire and terminal, the joint will in time develop high resistance as the metals oxidize. This type of joint is caused by insufficient heat during soldering and may be the result of too low a wattage soldering iron, by a copper bit that is too small, or poor contact between iron and joint. A cold solder joint may be repaired by reheating; however, it may be necessary to take the joint apart and resolder if dirt or oxide covers the wire.

A ROSIN joint is so named because the wire is held by rosin rather than solder. The flux is spread over the terminal, and instead of the solder bonding with the terminal, the solder settles on top of the rosin. The joint may have all the appearances of a good joint, but a little pressure will cause movement or an ohmmeter will indicate an open. A rosin joint occurs when using a "cold" iron or one that is too small. In most cases, merely applying a hot iron will clear up a rosin joint.

A DISTURBED solder joint has an irregular or crystallized appearance and the solder may be chipped off with a fingernail or a pointed tool. It is caused by the wire being moved before the solder has fully set. Since it may loosen later in service, it should be repaired in the same manner as the cold solder joint. This type of joint is often the source of noise in the equipment.

An INSUFFICIENT solder joint can introduce high resistance in the circuit and, as current flows, undesirable heat. It may loosen and cause an open or intermittent operation depending upon the amount of oxide present. This heat or a visual inspection may reveal this condition, but it may be necessary to use an ohmmeter to detect this type of solder joint. To repair it, it should be taken apart; and after cleaning off the oxide, the joint should be resoldered correctly.

A NO-SOLDER joint may cause noise due to oxide or vibration; the circuit may open entirely. A visual inspection and an ohmmeter will indicate this condition. The joint should be taken apart, cleaned, and then resoldered correctly. There are many other soldering defects, such as excessive solder, loose solder, and insulation too close or too far from joint. Invariably these defects can be traced to the technician making the connection.

Occasionally some special techniques are required in soldering. Such an occasion occurs in aviation fire control equipment using miniaturized components. In such equipment, the physical dimensions of resistors have greatly decreased and application of a soldering iron close to the body of these small carbon composition resistors causes a PERMANENT change in resistance. Overheating of these resistors and other components during soldering can be avoided only by restricting heat conduction along the terminating leads.

The most acceptable means of preventing this overheating is by use of a thermal shunt. Such a shunt is shown in fig-

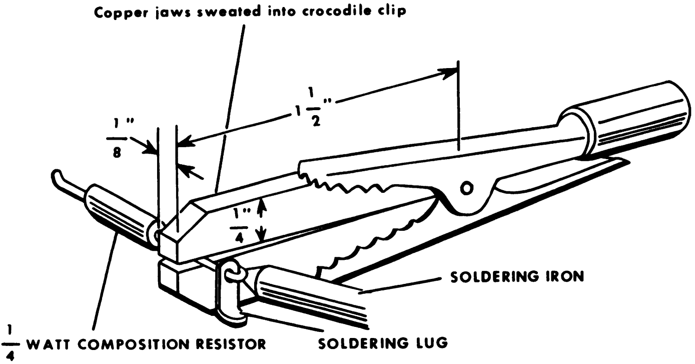

Copper jaws sweated into crocodile clip
1 1/2"
1/8"
1/4"
SOLDERING IRON
1/4 WATT COMPOSITION RESISTOR
SOLDERING LUG

Figure 9–17.—Details of clamp type shunt.

ure 9–17. This shunt should be placed as close to the resistor and as far from the joint as possible. Be certain that the clamp does not contact both the resistor and the joint. Some technicians use a pair of long nose pliers as shunts while soldering. The use of pliers has certain disadvantages but is fairly satisfactory for general-purpose occasional work.

Crimping

In aircraft electronic equipment almost all of the permanent connections are made by soldering. However, in the electrical SYSTEMS which are incorporated in the fire control systems, the permanent connections may be made by crimp-on terminals. This use of crimping is relatively new and is due to some of the limitations of soldered terminals. The quality of soldered connections depends mostly upon the operator's skill. Such factors as temperature, flux, cleanliness, oxides, and insulation damage due to heat also contribute to defective connections when they are not precisely controlled.

The crimp-on or solderless terminals require relatively little operator skill. Another advantage is that the only tool necessary is the crimping tool. The connections are made more rapid, clean, and uniform. Due to the pressures exerted and the materials used, the crimped connection or splice, properly made, has an electrical resistance that is less than that of an equivalent length of wire.

The basic types of terminals are shown in figure 9–18. (A) shows the straight type, (B) the right angle type, (C) the flag type, (D) the splice type, and (E) the disconnect splice type. There are also variations of these types, such as the use of a slot instead of a terminal hole, three and four-way splice type connectors, etc.

Since both copper and aluminum wiring is used in present aircraft, both copper and aluminum terminals are necessary. Various size terminal or stud holes will be found for each of the different wire sizes. A further refinement of the solderless terminals is the insulated terminal; the barrel of the terminal (fig. 9–18) is enclosed in an insulation material. The insulation is compressed along with the terminal barrel when crimping, but is not damaged in the process.

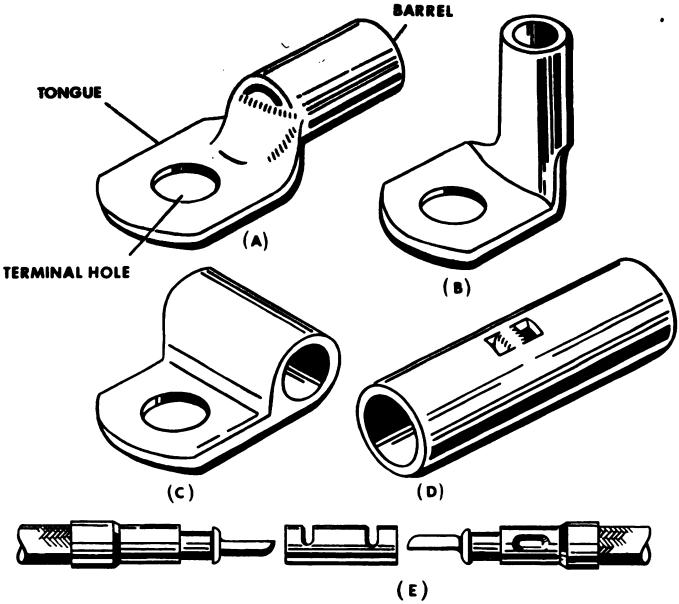


Figure 9–18.—Basic types of solderless terminals.

This eliminates the necessity of taping or tying an insulating sleeve over the joint.

There are two types of crimping tools used with copper terminals. For wire sizes AWG (American Wire Gage) 10 or smaller, a small pliers type of crimper is used. For the larger wire sizes, a large and powerful pincer type crimper is used. The small pliers type crimper has several sizes of notches for the different size terminals. The large pincer type is adjusted to an index mark for the different size terminals. Care should be exercised to select the correct crimping tool for the particular terminal.

The procedure for crimping a copper terminal to a copper wire is as follows:

1. The cable insulation should be stripped carefully to avoid cut or nicked strands. Insulation should be removed for the proper length.
2. Stranded wires should never be tinned. The solder forms a line of stress concentration on each strand and results in vibration failure.
3. Insulation-grip terminals should always be used for wire sizes No. 10 AWG and smaller, regardless of application, to protect conductors from mechanical vibration and fatigue.
4. The stripped cable end should always extend into the terminal barrel for the full length of the barrel.
5. The terminal barrel should be centered in the crimping tool so that pressure on the strands, from the crimped strands to the unsecured strands, will be gradual thus preventing stress concentrations.
6. Now crimp the terminal, making sure that the crimper is fully closed to insure proper crimping.
7. The joint should then be inspected with a probe through the inspection hole. The end of the conductor must come to the edge of the inspection hole.

Terminals that are used with ALUMINUM wire are made of aluminum and have been tinned by the manufacturer. Proper crimping is more difficult with aluminum terminals because of such factors as aluminum creep and softness. The softness of aluminum wire also makes it subject to being cut or nicked during stripping. Because aluminum terminals are used only with AWG size 8 and larger, the crimping tool is the large pincer type. You should be careful never to use an aluminum terminal with copper wire or a copper terminal with aluminum because of the battery effect. Also, never attempt to install any aluminum terminals with a copper crimping tool, and conversely, never use the aluminum crimping tool for crimping other than aluminum terminals.

The procedure for crimping an aluminum terminal to an aluminum wire is as follows:

1. The conductor insulation should be removed very carefully since cut or nicked aluminum conductors are NEVER acceptable.
2. Do not wire brush or scrape the aluminum conductor; the compound in the terminal barrel will satisfactorily clean it.
3. Remove the protective foil wrapping from the terminal and check the amount of compound in the terminal barrel. It should be 1/4 to 1/2 full.
4. Insert the stripped conductor the full length of the terminal barrel. While doing this, the thumb must be held over the inspection hole so that the compound is forced in and around the strands.
5. The terminal should be centered in the crimping tool.
6. Close the handle all the way, until the movable handle meets the stop.
7. After wiping off the excess compound, the joint should be inspected with a probe through the inspection hole. The end of the conductor should come to the edge of the inspection hole.

Care should be used in the procedure because improper procedures will eventually cause terminal failure. Be particularly careful of undercrimping, overcrimping, the use of the wrong crimping tool, improper cleaning methods, and cutting or nicking the conductors. A loose contact will allow an oxide film to form between the wire and terminal; this will result in increased resistance and the resistance will cause heat. The heat will accelerate the deterioration and eventually results in a failure. A lockwasher should never be used next to an aluminum terminal since it will gouge out the tinned area and thus increase deterioration. A flat washer should be used, thus preventing the revolving nut from scratching the tinned area or causing creep of the aluminum terminal.

If the correct tools are used, and the proper procedures followed, the connections will be more effective electrically, as well as mechanically, than soldered connections. A visual inspection is very important for it will reveal oxidation, deterioration, overheating, and broken conductors. In some cases it may be necessary to check these connections with an ohmmeter; the proper resistance, for all practical purposes, should be zero. Any defective terminal should be removed and a new terminal crimped on.

Safety Wiring

Screws, bolts, electrical and mechanical connectors, and other devices are safety wired as an additional security against the effects of vibration. The basic principles of safety wiring is shown in figure 9–19. The wire is threaded through the bolthead in such a direction that if a bolt tends to loosen, the wire will become tighter.

The wire used in safety wiring is usually made of annealed brass or annealed stainless steel. The size is not critical, depending mainly on the size of bolt being secured. The bolt used has a hole drilled through the head.

Referring to figure 9–19, the general procedure for safety wiring is as follows:

1. Thread the wire through the first bolt so that the wire exits on the side nearest the second bolt (point A).

2. Loop the wire around the side of the bolthead. The loop should be opposite the direction followed by the twisted wire so as not to interfere with it.

3. Never kink the wire as it will be weakened at this point.

4. Twist the wire with the hands; hold the wires so that an angle of about 90 degrees is formed between them. Do

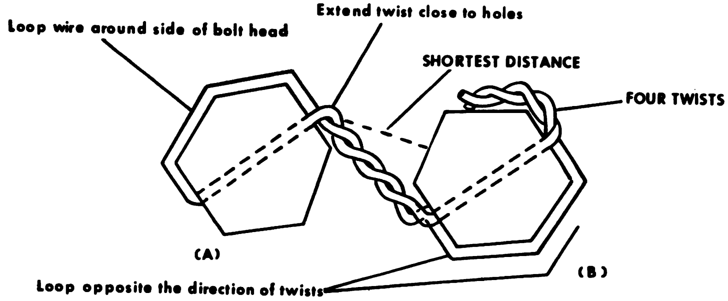

Loop wire around side of bolt head
Extend twist close to holes
SHORTEST DISTANCE
FOUR TWISTS
(A)
(B)
Loop opposite the direction of twists

Figure 9–19.—Safety wiring of bolts.

not use pliers as this tends to develop kinks and nicks, and to make the twist too small and tight.

5. One end is threaded through the second bolthead and the other end around the side of the bolthead that is opposite to the direction of the twisted wire.

6. Both ends are then pulled tight and given a minimum of four twists on the far side of the second bolt.

7. The wire is cut off and bent along the side of the bolthead.

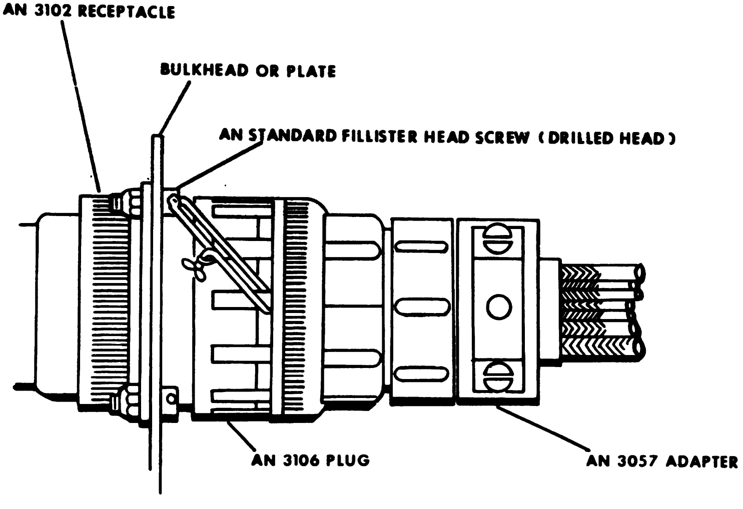


Figure 9–20.—Safety wiring attachment for plug connectors.

Under conditions of severe vibration, the coupling nut of the AN connector may vibrate loose; and with sufficient vibration, the connector will come apart. When this occurs, the circuit carried by the cable will open. The proper protective measures to prevent this occurrence is safety wiring as shown in figure 9–20.

The safety wire should be as short as practicable and must be installed in such a manner that the pull on the wire is in the direction which tightens the nut on the plug. In aviation fire control equipment there will be other parts and devices which require safety wiring o prevent loosening, parting, or changing of position. The procedure given for the safety wiring of bolts needs only slight modification to fit the particular situation. Whenever a safety wire is broken for maintenance or other cause, it must be replaced using the proper procedure. Any time a required safety wire is NOT replaced, an inflight failure may result.

Tying and Lacing

While making repairs or fabricating a new cable, it may be necessary for you to tie or lace the cable. The accepted method for lacing cable harnesses is shown in figure 9–21 (A). The use of the continuous lacing method is restricted to panels and junction boxes. The purpose of lacing is to keep all cables neatly secured in groups and to avoid possible damage from chafing against equipment or interference with equipment operation. When continuous lacing is used, it shall not include cables of more than one harness group.

Because continuous lacing has the disadvantage that if the cord is broken the lacing has a tendency to unravel, it is restricted in its use. In place of the continuous lacing, tying (or short-section lacing) is used. The method of tying in use is shown in figure 9–21 (B). In the first method, tie a clove hitch about the wires. Then tie a knot over the clove hitch in such a manner as to produce a square knot.

For aircraft wire lacing, nylon cord and cord meeting specifications MIL–C–572 and Jan T–713 are used. If you need additional information on tying and lacing refer to the

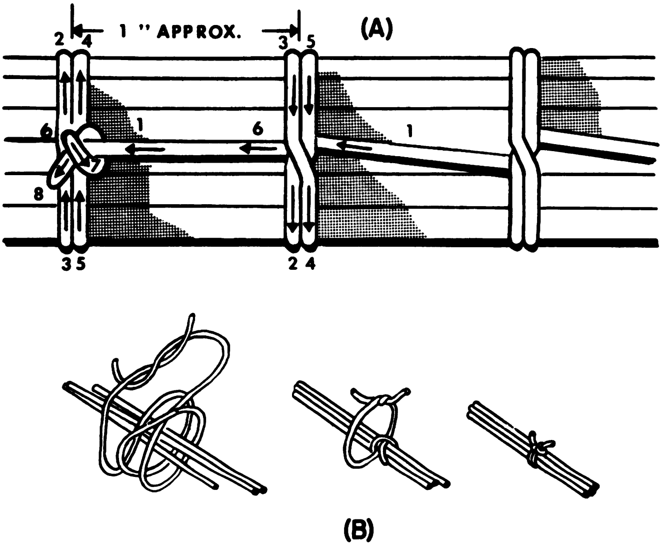


Figure 9–21.—Lacing and tying.

Handbook of Installation Practices for Aviation Electric and Electronic Wiring, NavAer 01–1A–505.

Shielding and Bonding

SHIELDING.—Shielding is the enclosing of cables or electrical units in metal to prevent high frequency interference. Shielding causes the high frequency voltage to be induced in the shield rather than in the units or cables. Shielding is used where a unit is to be protected from radiofrequency noise. It is also used to keep cables or units from emitting radiofrequency noise. Thus, shielding is used to keep outside noise out and inside noise in.

Formerly shielding was accomplished by shielding all the electronic and electrical equipment and their cables. In modern aircraft, the use of conduit has been eliminated wherever possible. In place of the conduit, the airplane is used to the best advantage as an electrical shield for the cable. Channels and even the surface covering of a metal aircraft provide excellent shielding. Thus, when replacing a cable, particular care must be taken to replace it in the exact position in which it was installed originally.

Where shielding of cables is used, it is very important that it be well grounded at each end of the cable. Radiating circuits such as pulse cables and transmission lines use coaxial cables. The outer flexible conductor of "coax" often serves as the shield, but occasionally an additional braid is used for shielding. Regardless of the system used, the conductor forming the shield is grounded at the connectors.

Disturbances caused by spark discharges are the most difficult to control. A spark discharge not only radiates but also causes voltage variations in the circuit. Shielding is effective for the radiations but not for line variations. These variations in the line can be smoothed out by the use of filters. The function of such filters is to block or bypass voltages and currents of frequencies which would cause interference.

BONDING.—Bonding straps are used to tie together electrically any parts of the airplane which are not already an integral part of the metal structure of the aircraft. Bonds are used, for example, to connect engine to mount, ailerons to wing, and sights and computers to airplane structure.

Some of the reasons for bonding are:

1. To minimize interference to electronic equipment by equalizing the static charges that accumulate.
2. To eliminate a fire hazard by preventing static charges from accumulating and creating a spark.
3. To minimize lightning damage to the aircraft and its occupants.
4. To provide a proper "ground" for electronic equipment.
5. To provide a low restistance return path for single wire electrical systems.
6. To aid in the effectiveness of shielding.

A bond is usually made of a flexible metal strap provided with crimped-on terminal at each end. It may be made of either aluminum or tinned copper wire. In bonding, be careful not to place the aluminum in contact with a dissimilar metal, for the contact of brass, bronze, copper, or steel with

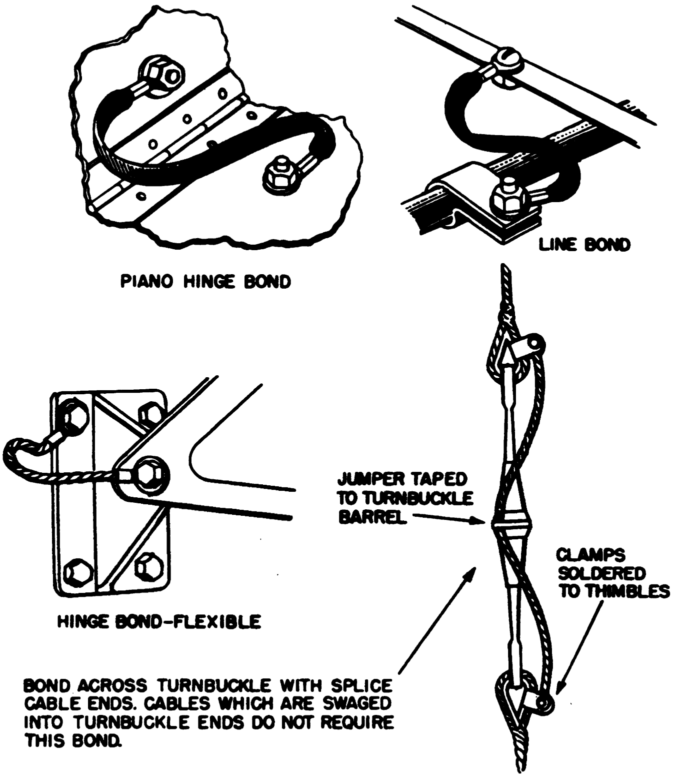

PIANO HINGE BOND
LINE BOND
HINGE BOND-FLEXIBLE
JUMPER TAPED TO TURNBUCKLE BARREL
CLAMPS SOLDERED TO THIMBLES
BOND ACROSS TURNBUCKLE WITH SPLICE CABLE ENDS. CABLES WHICH ARE SWAGED INTO TURNBUCKLE ENDS DO NOT REQUIRE THIS BOND.

Figure 9–22.—Bonding methods.

aluminum will result in corrosion, especially in the presence of moisture (battery effect). Some of the bonding methods are shown in figure 9–22. Another type, not shown, is the quick-disconnect variety. These are used ONLY for bonding parts which are frequently removed for servicing.

The bond must be intact and make a good electrical connection at all times. In replacing a bond, be careful to make a good metal contact. If, in preparing the surface for the bonding connection, you have to clean the surface with sandpaper, be sure not to damage the original finish on the metal. Place bonds in such a position that they will not interfere with the operation of the unit and will not be damaged or broken loose because of the motion or vibration of the unit.

Cable Splicing

Cable splices, other than the pre-insulated crimp-on splices or connectors shall not be used except as an EMERGENCY measure.

If an emergency condition exists solder may or may not be used, as the condition warrants, but in any case the splice should give a good electrical and mechanical joint without solder. The splice should be taped to give insulation equivalent to the rest of the cable. A permanent repair must be made as soon as it is possible.

Ordinarily there is not enough slack wire for making splices. However if there is enough slack, the two splices used by the Aviation Fire Control Technician will be the "western union splice" and the "flexible wire splice." These and other splices and joints are covered in *Basic Electricity*, NavPers 10086, chapter 6.

Moistureproofing

As a result of corrective maintenance experiences with electrical connectors, SEALING (or moistureproofing) of these connectors has become a very important preventive maintenance factor. The sealing compound is used on connectors to protect them from corrosion or contamination by preventing metal particles and liquids from entering. Also, the sealant reinforces the back of connectors against failure caused by vibrations and other lateral pressures which may fatigue the wire at the solder cup. Further, the compound has improved dielectric characteristics which reduce the probability of arc-over between pins on the back of the connector.

As an AQ in an operating organization, the majority of your use of a sealing compound will be reserved for the replacement of failed or corroded electrical connectors. Occasionally you may be called upon to make new installations, following definite instructions. The sealant is provided in kit form through the normal supply channels. Sealing (or potting, as it is called) is not required on environment proof type and "E" connectors or on coaxial cable connectors. In this sealing operation, the current Electronic Material Change (E. M. C. No. 89–55) will provide detailed information and MUST be followed.

Let us now briefly summarize the sealing procedure in the preparation of a used connector.

1. Prepare the connector by removing existing sealants and cleaning. The cleaning solvent used must clean thoroughly, evaporate quickly, and leave no residue. Remove all sleeving from the wires. Resolder loose or poorly soldered connections and add a length of wire approximately 9 inches long to each unused pin. Remove any excess rosin from around the pins and the insert; a stiff bristle brush is helpful in doing this. Now, repeat the cleaning; and separate the wire evenly.

2. Thoroughly mix the accelerator and base compound. The ratio of the amount of accelerator to base compound is critical; therefore the entire quantity of accelerator furnished must be added to the base compound.

3. Place the plugs or receptacles on a table, arranging them so that gravity will draw the sealer to the bottom of the plug. Box receptacles or plugs without back shells must be fitted with a mold formed from masking or cellophane tape or equivalent, to retain the sealant during the curing process. If the back shell is used, apply a slight amount of oil to the inner surfaces to prevent the compound from adhering to it.

4. The compound is applied by a spatula, putty knife, or paddle. It should be packed around the base of the pins. The part being potted should be completely filled or at least to a point to cover ⅜ inch of insulated wire. The compound is now allowed to cure; temperature will affect the curing time. The normal curing time is approximately 24 hours.

If it is desired that the entire connector assembly (plug and receptacle) be sealed against fluid entering or collecting between the two parts, it is necessary that a rubber O-ring be fitted over the barrel of the plug. This will provide a seal when the two parts are engaged securely. If properly installed, this seal will prevent moist air from entering due to variations in temperature, atitude, or barometric pressure on the ground. Rubber packing O-rings are available for this purpose through normal supply channels. Due to the aging of the rubber O-rings in service, it is necessary to examine them each time the connector is disassembled. If deteriorated, they must be replaced.

The purpose of soldering a short length of wire to each spare pin is to provide for two eventualities: to allow for growth requiring additional circuits to be included in the connector, or to reduce the need of repairing a single wire which may have failed within the connectors by making a splice to one of the spare wires. In the event a spare wire is not available in the connector and a single wire must be replaced, the back shell may be removed. This may require considerable force depending on how well the sealant adheres.

Access to the desired lead and solder cup may be obtained by cutting away the compound with a knife. If a center wire of a large connector is defective, beyond easy reach from the side, it may be better to remove the sealant from the center with long nose pliers until sufficient area is exposed to allow the defective lead to be repaired. A small soldering iron or soldering gun is required when working in confined places. Complete removal of the compound may be necessary. The plug may be returned to its original condition by applying sealant to the connector in the manner previously described. The new compound will seal or vulcanize satisfactorily any old compound remaining in the connector.

QUIZ

1. The magnetomotive force (m. m. f.) which produces the magnetic flux in a solenoid is expressed in
   a. volts
   b. ampere turns
   c. ohms
   d. amperes
2. The first step to be taken in checking an improperly operating solenoid is to
   a. disassemble the solenoid
   b. measure the resistance
   c. make a good visual inspection
   d. measure the current through the solenoid
3. The result of several shorted turns in a solenoid would be
   a. faster action of the solenoid
   b. increased voltage across the solenoid
   c. decreased current through the solenoid
   d. increased current through the solenoid
4. The two most common electric protective devices used in aircraft are
   a. fuses and circuit breakers
   b. relays and solenoids
   c. switches and meters
   d. plugs and connectors
5. The most common overcurrent device used in electric circuits is a/an
   a. ammeter
   b. relay
   c. fuse
   d. switch
6. The voltage rating of a fuse is the voltage that
   a. appears across the fuse before the fuse opens
   b. appears across the fuse after the fuse opens
   c. the fuse can safely handle without arcing after the fuse opens
   d. the fuse can safely handle without arcing before the fuse opens

7. The advantage of the circuit breaker over the fuse in an electrical circuit is that it
    a. is easier to replace
    b. can handle more current
    c. can withstand more voltage
    d. can be reset and used again

8. A toggle switch which is spring loaded to the OFF position and must be held in the ON position to complete the circuit is called a
    a. single-position switch
    b. two-position switch
    c. double-pole, double-throw
    d. double-throw switch

9. The function of a control relay is to control
    a. a small amount of power with a large amount of power
    b. a large amount of power with a small amount of power
    c. the amount of voltage in a circuit
    d. the amount of current in a circuit

10. What type of relays were developed to answer the demands of most modern aircraft equipment?
    a. Semisealed
    b. Hermetically sealed
    c. Open
    d. Gasket type sealed

11. An advantage of the rotary type relay over the clapper type is that it
    a. is less sluggish
    b. requires less power to operate
    c. is smaller in size
    d. has greater vibration and shock resistance

12. The purpose of the shading coil in an a-c relay is to
    a. prevent the relay from chattering
    b. strengthen the magnetic field
    c. change the a. c. to d. c. in order to operate the relay
    d. decrease the sluggishness of the relay

13. A rheostat is normally used
    a. to adjust current
    b. to adjust voltage
    c. across the load
    d. across the voltage source

14. A potentiometer that has an even distribution of resistance across its entire length is called a
    a. straight-line potentiometer
    b. tapered potentiometer
    c. linear potentiometer
    d. square law potentiometer

15. The main advantage of the carbon potentiometer over the wire wound potentiometer is that it is
    a. capable of handling more current
    b. less expensive
    c. more accurate
    d. easier to repair

16. When an electrical wire installed in an aircraft becomes defective, the action should be to
    a. cut out defective portion and splice in new portion
    b. tape up defective portion of wire
    c. install a new wire parallel to the defective wire
    d. replace defective wire with new wire of same type and length

17. In the standard color code for chassis wiring, RED is the color for
    a. power supply B plus
    b. cathodes
    c. plates
    d. screen grids

18. In the identification of AN connectors, type AN 3101 refers to
    a. wall-mounted receptacles
    b. cable-connecting receptacles
    c. box-mounting receptacles
    d. straight plugs

19. Coaxial cables are used instead of regular cables in certain applications because of its
    a. weatherproof outer covering
    b. excellent shielding qualities
    c. low attenuation of high frequencies
    d. high current carrying capacity

20. In the maintenance of cables and connectors, the first consideration is a/an
    a. ohmmeter check
    b. voltage check
    c. thorough visual inspection
    d. vibration check

21. In soldering electrical connections, use only
    a. hard solder
    b. rosin flux
    c. acid flux
    d. a soldering gun

22. A COLD solder joint is caused by
    a. the wire being moved before the solder has fully set
    b. the solder settling on top of the flux
    c. oxidation of the joint
    d. insufficient heat during soldering

23. In crimping terminals an aluminum terminal should never be used with a copper wire or vice versa because
    a. of the battery effect
    b. aluminum is softer than copper
    c. copper carries more current than aluminum
    d. aluminum is more expensive than copper

24. When safety wiring a bolt, care must be taken to
    a. never kink the wire
    b. twist the wire tight with pliers
    c. use hard drawn brass wire
    d. use hard drawn stainless steel wire

25. Where shielding of cables in aircraft is used, it is very important that the shield be grounded
    a. at each end
    b. in the middle
    c. on either end
    d. at any place along the length of the cable

CHAPTER 10

ELECTRICAL MAINTENANCE

An understanding of the principles and operation of aviation fire control equipment as presented in the preceding chapters forms a portion of the knowledge necessary for successful maintenance of the equipment. A knowledge of electrical maintenance procedures is also needed to perform this task. The device most often used in electrical maintenance is the meter. For this reason, we shall first review meters. For a complete discussion of meters, you are referred to chapter 9 of *Basic Electricity.*

REVIEW OF METER OPERATION

It is appropriate to emphasize that a thorough understanding of the construction, operation, and LIMITATIONS of electrical measuring instruments, coupled with the theory of circuit operation, is most essential in servicing and maintaining electrical equipment. Remember that the best and most expensive measuring instrument is of NO use to the man who does not know what he is measuring or what the readings indicate.

The three types of meters that the AQ3 will encounter are ammeter, ohmmeter, and voltmeter. All three types normally employ the permanent magnet moving coil (Weston) meter movement. It is well to pay special attention to each application in this review.

The AMMETER is an instrument used to measure current. The AQ3 will utilize the ammeter to acquire further information while performing an operational check on a malfunctioning aviation fire control system to further localize the malfunction to a specific UNIT. The ammeter must always be placed in series with the circuit to be measured. The ammeter consists of a basic meter movement and a combination of shunt resistors placed in parallel with the meter movement. A multiposition switch or a series of pin jacks is used to allow the use of various sizes of shunt resistors to give different current ranges. When using an ammeter, always have the meter on the highest range before connecting it to an energized circuit.

The OHMMETER is widely used by the AQ3 in making resistance measurements and continuity checks. He will find wide use for this instrument in checking cables and locating malfunctioning components in electrical circuits. The ohmmeter consists of a basic meter movement connected as an ammeter, a voltage source, and one or more resistors used to adjust the current through the meter movement. The meter must be adjusted for "zero resistance" prior to making resistance measurements. Care must also be exercised not to use an ohmmeter on an energized circuit.

The VOLTMETER utilizes the basic meter movement by placing a high resistance in series with it. The value of this series resistance is determined by the current necessary for full-scale deflection of the meter and the voltage being measured. Because the current is directly proportional to the voltage applied, the scale can be calibrated directly in volts for a fixed series resistance.

The SENSITIVITY of voltmeters is given in ohms per volt, and may be determined by dividing the resistance of the meter plus the series resistance by the full-scale reading in volts. This is the same as saying that the sensitivity is equal to the reciprocal of the current (in amperes). Thus, the sensitivity of a 100-microampere movement is the reciprocal of 0.0001 ampere or 10,000 ohms per volt. The sensitivity of the meter depends on the strength of the permanent magnet field and the weight of the moving coil.

The sensitivity of a voltmeter is an identification of how accurately it measures voltages in a circuit. In many cases, a sensitivity of 1,000 ohms per volt is satisfactory; however, if the circuit in which the voltage is being measured has high resistance, a greater sensitivity is required for accuracy. The higher the sensitivity rating, the higher the resistance in the meter branch of the circuit, and the less the possibility of the meter shunting the circuit. If a meter of low ohms per volt used to measure the voltage in a high resistance circuit, the meter will shunt the load being measured and result in an inaccurate reading. Thus, the higher the sensitivity, the more accurate the reading.

Like the ammeter and ohmmeter, the voltmeter normally utilizes several resistors with a switching arrangement to permit multirange operation. The importance of setting the selector switch for maximum voltage range before connecting it to an energized circuit cannot be overemphasized.

Multimeters

During troubleshooting, a technician is often required to measure voltage, current, and resistance. To eliminate the necessity of obtaining three or more meters, the multimeter is used. The multimeter combines a voltmeter, ammeter, and ohmmeter in one unit. It includes all the necessary switches, jacks, and additional devices. By proper arrangement of parts, the multimeter can be built into a small, compact unit utilizing one meter movement.

A typical multimeter circuit is shown in figure 10–1. A

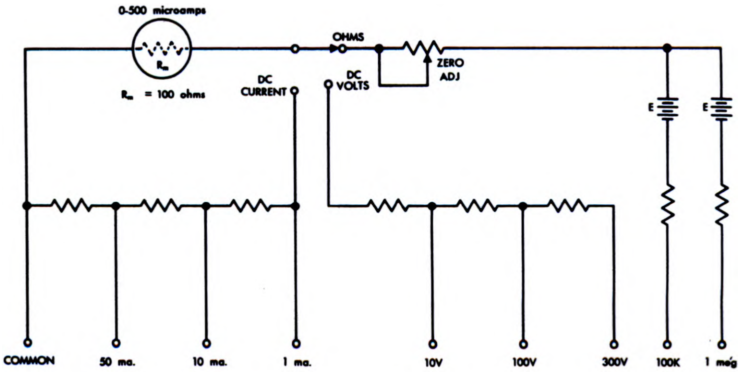


Figure 10–1.—A typical multimeter circuit.

three-range milliameter, a three-range voltmeter with a sensitivity of 2,000 ohms per volt, and a two-range ohmmeter are combined in this circuit. A 0–500 microampere meter movement with a resistance of 100 ohms is the basic meter movement for this multimeter.

Use of Meters

The following are guides for the proper use of meters:

1. An ammeter is always connected in series and NEVER in parallel.
2. A voltmeter is connected in parallel.
3. An ohmmeter is NEVER connected to a live circuit.
4. Polarity must be observed in the use of an ammeter or a d–c voltmeter.
5. Meters should be viewed directly from the front. When viewed from an angle off to the side, an incorrect reading will result because of parallax.
6. Always choose an instrument suitable for the measurement desired.
7. Select the highest range FIRST and then switch to the proper range.
8. In using an ammeter or voltmeter, choose a scale which will result in an indication as near midscale as possible.
9. In using an ohmmeter, select a scale which will result in a midscale reading.
10. Do not mount or use instruments in the presence of a strong magnetic field, such as those surrounding a magnetron installation.
11. Do not expect to obtain a meter accuracy greater than the guaranteed limits.
12. Remember, a low internal resistance voltmeter (low sensitivity) may shunt the circuit being measured and result in incorrect readings.

VACUUM TUBE VOLTMETER

Voltmeters can be divided into two general types, direct indicating and indirect indicating. The direct indicating, as previously discussed, must take the power necessary to operate the meter movement from the measuring source. Therefore, it is limited in its application by the sensitivity of the movement. It is also limited in a-c measurements since its frequency handling capabilities are limited by the shunting effect of the capacity between the plates of the metallic oxide rectifier.

The indirect indicating type meter utilizes an external power supply to operate the meter movement. The current from this power supply is controlled by a power amplifier which, in turn, is controlled by the voltage being measured.

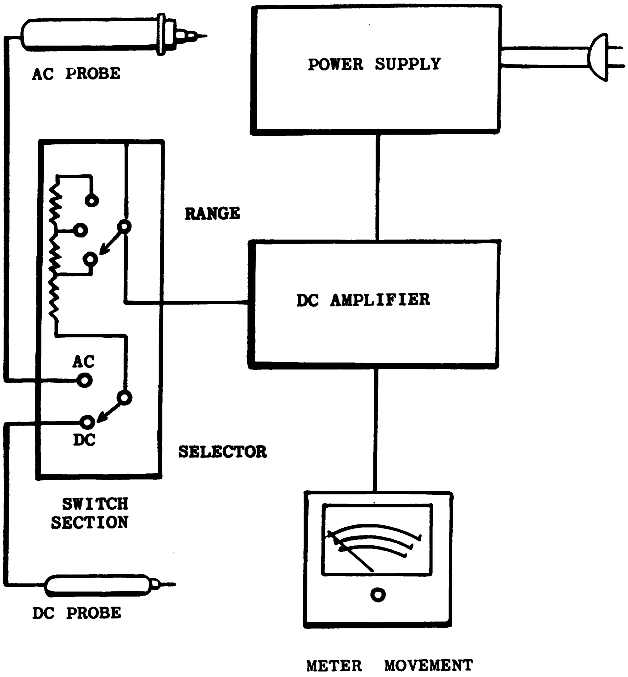


Figure 10–2.—Block diagram of a vacuum tube voltmeter.

Since only a very small amount of power is required to control the power amplifier, this type of meter utilizes a very low current rectifier, such as a small vacuum tube or crystal diode. The vacuum tube or crystal diode has very little capacitance, thus, little shunting effect. This allows a-c voltages at frequencies of 100 megacycles per second or greater to be accurately measured.

A simplified diagram of a meter utilizing this principle is shown in figure 10–2. Current to operate the indicator is supplied by the power supply. However, it must pass through the d-c amplifier, the resistance of which is controlled by the voltage from the switch section. The input resistance of the d-c amplifier is relatively high. Thus, when connected in series with resistance of the switch section and the probe, it has very little loading effect on the circuit being tested.

A typical vacuum tube voltmeter that is frequently employed in the maintenance of Navy electronic equipment is shown in figure 10–3. This meter was designed especially for military use and built to withstand rugged use. The meter differs from those previously discussed in that it has a-c and d-c probes built in and electrically connected. This is in addition to the a-c and d-c terminals.

A description of the meter controls and their operation is as follows:

D-C PROBE—test probe used for measuring d-c voltages. It can be used in any d-c measurement, but must be used when measuring a d-c voltage in a circuit containing r-f energy.

A-C PROBE—test probe for measuring a-c voltages. It can be used in any a-c voltage measurement at frequencies over 10 kc., but must be used when measuring voltages with frequencies above 50 kc.

Note: Ground terminal must be connected to the unit being tested when using either probe.

D-C PANEL TERMINALS — used for measuring d-c voltages. The ground terminal must also be connected as with any meter, and the D-C PROBE must be in its clip before the panel terminals can be used.

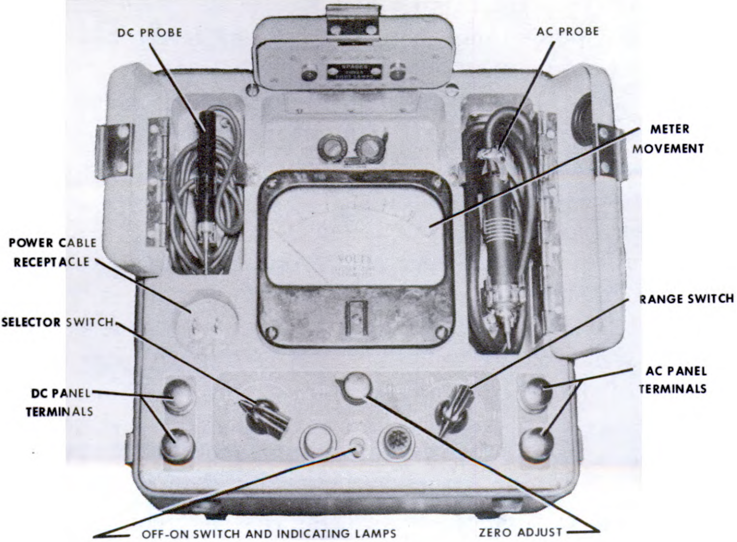


Figure 10–3.—Vacuum tube voltmeter TS–375/U.

A-C PANEL TERMINALS—used when measuring a-c voltages with frequencies from 40 c. p. s. to 50 kc. The ground terminal must be connected and the **A-C PROBE** in its clip before the a-c terminal can be used.

POWER CABLE RECEPTACLE—must be supplied with 105 to 125 volts a. c., 50 to 1,600 c. p. s.

ZERO ADJUST—used to calibrate the amplifier to the meter movement at zero voltage reading, prior to making voltage measurements.

LINE SWITCH—applies power to the power supply. The lamps on either side of the switch indicate when power is applied (red) or when on standby (white).

SELECTOR SWITCH—selects a-c or d-c operation with provisions for positive or negative d-c measurements.

RANGE SWITCH—selects the voltage range for either a. c. or d. c.

For more detailed information on the TS–375/U refer to the *Handbook of Maintenance Instructions*, AN 16–35TS375–3.

TECHNIQUES FOR METER USE

We have considered meters, now let us consider some of the techniques employed in their use. The techniques suggested here are not all inclusive. You will find, as you develop your technical skill, there are other variations and techniques in use. As an example, consider the techniques for measuring current in a circuit. This can be done by placing an ammeter in series. It can also be accomplished by measuring the voltage across a resistor of known value. Then by application of Ohm's law, the current in the circuit can be calculated. This last technique has the advantage of eliminating the necessity of opening the circuit for placement of the ammeter.

Continuity Test

Open circuits are those in which the flow of current is interrupted by a broken wire, defective switch, or any means by which the current cannot flow. The test used to check for opens (or to see if the circuit is complete or continuous) is called CONTINUITY TESTING.

An ohmmeter (which contains its own batteries) is excellent for a continuity test. In an emergency a continuity tester can readily be made from a flashlight. Normally, continuity tests are performed in circuits where the resistance is very low (such as the resistance of a copper conductor). An open is indicated in these circuits by a very high or infinite resistance. Such a condition would be an open conductor.

The diagram in figure 10–4 shows a continuity test of a cable. Notice that both connectors are disconnected and the ohmmeter is in series with the conductor under test. The power should be off. Checking conductors A, B, and C, the current from the ohmmeter will flow through plug No. 2, through the conductor, and plug No. 1. From this plug it will pass through the jumper to the chassis which is "grounded" to the aircraft's structure. The structure will serve as the return path to the chassis of unit 2 completing the circuit to the ohmmeter. The ohmmeter will indicate a low resistance.

Checking conductor D in figure 10–4 will reveal an open. The ohmmeter will indicate maximum resistance because current cannot flow. With an open circuit, the ohmmeter needle is all the way to the left since it is a series type ohmmeter (reads right to left).

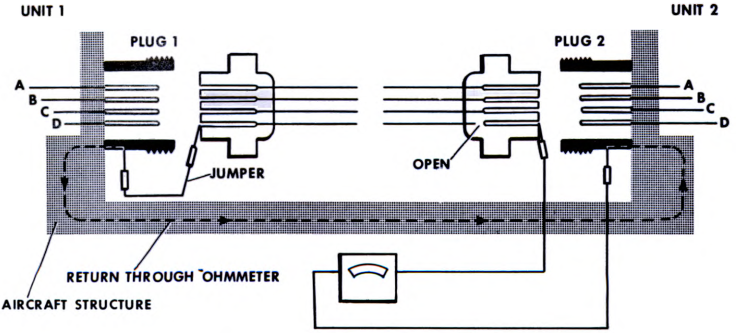


Figure 10–4.—Continuity test.

Where conditions exist that the aircraft structure cannot be used as the return path, one of the other conductors may be used. For example (referring to figure 10–4), to check D a jumper is connected from pin D to pin A of plug 1 and the ohmmeter leads are connected to pins D and A of plug 2. This technique will also reveal the open in the circuit.

Test for Grounds

Grounded circuits are caused by some conducting part of the circuit making contact either directly or indirectly with the metallic framework of the airplane. Grounds may have many causes, the most common of which is perhaps the fraying of insulation from a wire allowing the bare wire to come in contact with the metal ground.

Grounds are usually indicated by blown fuses or tripped circuit breakers. Blown fuses or tripped circuit breakers, however, may also result from a short other than ground. A high resistance ground may also occur where not enough current can flow to rupture the fuse or open the circuit breaker.

In testing for grounds, the ohmmeter is used. Other continuity testers many also be used. By measuring the resistance to ground of any point in a circuit, it is possible to determine if the point is grounded. By considering figure 10–4, one possible means of testing a cable for grounds can be seen. If the jumper is removed from pin D of plug No. 1, a test for grounds is made for each conductor of the cable. This is accomplished by connecting one meter lead to ground and the other to each of the pins of one of the plugs. A low resistance will indicate that a pin is grounded. Both plugs must be removed from their units; if only one plug is removed, a false indication is possible for a conductor may be grounded through the unit.

Test for Shorts

A short circuit, other than a grounded one, is one where two conductors accidentally touch each other directly or through another conducting element. Two conductors with frayed insulation may touch and cause a short. Too much solder on the pin of a connector may short to the adjacent pin. In a short circuit enough current may flow to blow a fuse or open a circuit breaker. However, it is entirely possible to have a short between two cables carrying signals; such a short will not be indicated by a blown fuse.

As when checking for a ground, the device used for checking for a short is the ohmmeter. By measuring the resistance between two conductors a short between them may be detected by a low resistance reading. In figure 10–4 by removing the jumper and disconnecting both plugs, a short test may be made. This is performed by measuring the resistance between the two suspected conductors.

Shorts are not reserved for cables, they occur in many components, such as transformers, motor windings, capacitors, etc. The major test method for detecting such components is a resistance measurement, and then comparing the indicated resistance with the resistance given on schematics or in maintenance manuals.

Voltage Test

The voltage test must be made with the power applied; therefore, the prescribed safety precautions MUST be followed to prevent injury to personnel and damage to the equipment. You will find in your maintenance work that the voltage test is of utmost importance. It is used not only in isolating casualties to major components but also in the maintenance of subassemblies, units, and circuits. Before checking a circuit voltage, a check on the voltage of the power source should be made to be sure that the normal voltage is being impressed across the circuit.

Obviously, the voltmeter is used for voltage tests. In using the voltmeter make certain that the meter used is designated for the type current (a. c. or d. c.) to be tested and has a scale of adequate range. Since defective parts in a circuit may cause higher than normal voltages to be present at the point of test, the highest voltmeter range available should be used at first. Once a reading has been obtained, determine if a lower scale can be employed without damaging the meter movement. If so, use the lower scale, so as to obtain a more accurate reading.

Another consideration in the circuit voltage test is the resistance and current in the circuit. A low resistance in a high current circuit would result in considerable voltage drop; whereas, the same value resistance in a low current circuit may be negligible. Abnormal resistance in part of a circuit can be checked either with an ohmmeter or voltmeter. Where practical, an ohmmeter should be used, in that the test is then carried out with the circuit "dead."

The majority of the circuits encountered in aviation fire control equipment will be low current circuits, and most voltage readings will be d.c. Also many of the schematics indicate the voltages at many test points. Thus if a certain stage is suspected and you desire to check the voltage, a voltmeter placed from the test point to ground should read the voltages as given on the schematic.

Many maintenance manuals also contain voltage charts where all the voltage measurements are tabulated. These charts usually indicate the sensitivity of the meter used to obtain the voltage readings for the chart. To obtain comparable results, the technician must use a voltmeter of the same sensitivity as that specified. Make certain that the voltmeter is not loading the circuit while taking a measurement. If the meter resistance is not considerably higher than the circcuit resistance, the reading will be markedly lower than the true circuit voltage. (To calculate the meter resistance, multiply the rated ohms per volt sensitivity value of the meter by the scale in use. For example, a 1,000 ohms per volt meter set to the 300-volt scale will have a resistance value of 300.000 ohms.)

Resistance Test

Before checking the resistance of a circuit or of a part, make certain that the power has been turned off and capacitors in the associated circuit are discharged. To check continuity, always employ the lowest ohmmeter range. If a high range is used, the meter may indicate zero even though appreciable resistance is present in the circuit. Conversely, to check a high resistance, use the highest scale, since the low range scale may indicate infinity though the resistance is less than a megohm.

In making resistance tests, take into account that other circuits may be in parallel with the circuit to be measured. In which case an erroneous conclusion may be drawn from the reading obtained. To obtain an accurate reading if other parts are connected across the suspected circuit, one end of the circuit to be measured should be disconnected from the equipment. For example, many of the resistors in major components and subassemblies are connected across transformer windings. To obtain a valid resistance measurement, the resistor to be measured must be isolated from the shunt resistances.

Resistance tests are also used for checking a part for grounds. In these tests, the parts should be disconnected from the rest of the circuit so that no normal circuit ground will exist. It is not necessary to dismount the part to be checked. The ohmmeter, which is set for a high resistance range, is then connected between ground and each electrically separate circuit of the part under test. Any resistance reading less than infinity indicates at least a partial ground. Capacitors suspected of being short circuited can also be checked by a resistance measurement. To check a capacitor suspected of being open, temporarily shunt a known perfect capacitor across it, and recheck the performance of the circuit.

USE OF THE MEGGER

A thorough discussion of the operating principles of the megger is found in chapter 9 of *Basic Electricity.* Briefly a megger is an instrument for measuring very high resistance (therefore, insulation resistance). It consists of a hand-driven, d-c generator and a suitable indicating meter together with the necessary resistors. The name MEGGER is derived from the fact that it measures resistances of many megohms.

The need for such an instrument exists because ohmmeters will not accurately measure these high resistances. The low voltage contained in an ohmmeter is not sufficient to move enough current through high resistances. The generator within the megger will supply enough voltage to cause a measurable amount of current to flow; the meter indications will be in ohms.

There are various resistance ratings of meggers with full scale values as low as 5 megohms, and as high as 10,000 megohms. Figure 10–5 shows the scale of a 100-megohm, 500-volt megger. Notice that the upper limit is INFINITY and that the scale is crowded at the upper end. The first scale marking below infinity represents the highest value for which the instrument can be accurately used. Thus, if the pointer goes to infinity while making a test, it means only that the resistance is higher than the range of the set use.

There are also various voltage ratings of meggers (100, 500, 750, 1,000, 2,500, etc.). The most common type is the one with a 500-volt rating. This voltage rating refers to the maximum output voltage of the megger. The output

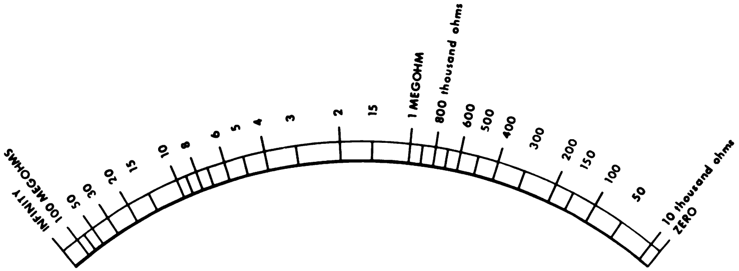


Figure 10–5.—Scale of 100-megohm, 500-volt megger.

voltage is dependent upon the speed of turning of the crank and armature. When the megger's armature rotation reaches a predetermined speed, a slip clutch will maintain the armature at a constant speed. The voltage rating is important, for the application of TOO high a voltage to even a good component will cause a breakdown. In other words, do not use a 500-volt megger to test a capacitor rated at 100 volts.

Meggers are used to test the insulation resistance of conductors in which shorting or breaking down under high voltage is suspected. In some situations, meggers are used in the prevention of unnecessary breakdowns by maintaining a record of insulation resistance of power and high voltage cables, motor and generator windings, and transmission lines. These records will reflect fluctuations in resistance and aid in determining when the components should be replaced to prevent a breakdown.

Meggers are used for testing capacitors whose peak voltages are not below the output of the megger. They are also used for testing for high resistance grounds or leakage on such devices as antennas and insulators.

PRECAUTIONS.—Precautions to be followed in the use of the megger are listed below:

1. When making a megger test, the equipment must NOT be live. It must be disconnected entirely from the system before it is tested.

2. Observe all rules for safety in preparing equipment for test and in testing, especially when testing installed high voltage apparatus.

3. Use well-insulated test leads, especially when using high range meggers. After the leads are connected to the instrument and before connecting them to the component to be tested, operate the megger and make sure there is no leak between the leads. The reading should be infinity. Make certain the leads are not disconnected or broken by touching the test ends of the leads together while turning the crank SLOWLY. The reading should be approximately zero.

4. When using high range meggers, take proper precautions against electric shock, especially while the component is under test. There is sufficient amount of capacitance in most electrical equipment to "store up" enough energy from the megger generator to give a very disagreeable and even dangerous electric shock. Owing to a high protective resistance in the megger, its open circuit voltage is not as dangerous, but care should be exercised.

5. Equipment having considerable capacitance should be discharged before and after making megger tests in order to avoid the danger of receiving a shock. This can be accomplished by grounding or short circuiting the terminals of the equipment under test.

TUBE TESTING

Although each electron tube purchased by the Navy has been thoroughly tested electrically and mechanically, it is possible, nevertheless, for tubes to be damaged in shipment, storage, or handling. Therefore, a tube should be tested before it is used the first time.

Electron tubes do not last indefinitely. Coated cathodes lose their power to emit electrons because the coating flakes off. Likewise, impregnated emitters of filament type tubes become depleted with age. There are other factors that cause electron tubes to function improperly—for example, defective seals permit air to leak into the tube and "poison" the emitting surface, and vibration or excessive voltage may cause internal shorts or opens. Whenever electronic equipment operates subnormally one of the first maintenance procedures is to check the tubes with a tube tester. This often results in finding weak tubes and replacing them prior to failure. As an AQ3, you are responsible for operating tube testers.

Types of Testers

Two types of tube testers are in general use. One type, the EMISSION-TYPE tester, indicates the relative value of a tube in terms of its ability to emit electrons from the cathode. The second and more accurate type is the MUTUAL-CONDUCTANCE (or transconductance) tube tester. This tube tester not only gives an indication of the electron emission, but also indicates the ability of the grid voltages to control the plate current.

The end of the useful life of a tube is usually preceded by a reduction in electron emissivity—that is, the cathode no longer supplies the number of electrons necessary for proper operation of the tube. In the emission tester, the proper voltages are applied to each electrode in the tube, and a meter indicates the plate current. If the tube has an open element or is at the end of its useful life, the emission tester gives an indication of this defect in the lower, or reject, portion of the meter scale.

A tube may have normal emission and still not operate properly because tube efficiency depends on the ability of the grid voltage to control the plate current. The emission-type tester indicates only the plate current and not the ability of the grid to control the plate current. The transconductance-type tube tester, however, indicates how the tube operates, not merely the condition of the emitting surface.

The terms "mutual conductance" and "transconductance" are used interchangeably in many texts. The Navy Department prefers transconductance, but many commercial tube testers are marked "mutual conductance."

When the prefix "dynamic" is used, as in "dynamic transconductance," it means that the characteristics of the tube in operation are being tested. The difference between the dynamic and static characteristics lies in the effect produced by the load impedance on the operation of the tube. Most tube testers, other than the emission type, test the dynamic characteristics by placing the tube in a working circuit.

Typical Tube Tester

The tube tester shown in figure 10–6 is a typical portable tube tester of the dynamic mutual-transconductance type designed to test electron tubes of the receiving types and many of the smaller transmitting types. A multimeter section, using the same indicator, is also incorporated in the equipment to permit measurements of a-c and d-c volts, d-c mils, and resistance and capacitance in a number of ranges.

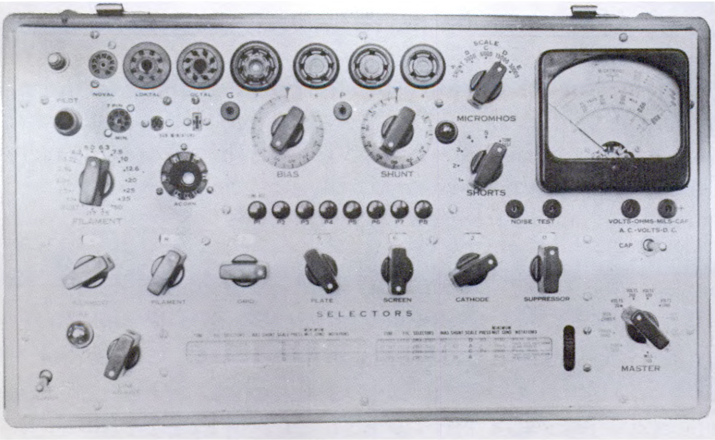


Figure 10–6.—Tube tester.

Let us now consider each of the individual tests performed by the instrument one at a time. These tests are: (1) line voltage test, (2) short circuit test, (3) noise test, (4) voltage test, (2) short circuit test, (3) noise test, (4) rectifier test, (5) mutual-conductance test, (6) gas test, and (7) tests performed by means of the multimeter section.

The tube tester has a roller chart indicating the tubes that may be tested. Listed opposite the tube designations is a series of numbers and letters which indicate the position of each switch and potentiometer of the SELECTORS and also the correct pushbutton to push. These switch positions connect the tube into a circuit that is comparable to the operating circuit of the tube. When the potentiometers are adjusted to the values indicated on the chart, the correct operating voltages are applied to the tube in order that it can be checked under operating conditions. As newer tubes than those listed on the roller chart are used in equipments, other charts are published giving the new switch positions and potentiometer settings. When conditions warrant, new roller charts incorporating the latest tubes are prepared.

LINE VOLTAGE TEST.—It is necessary to maintain rated voltage across the primary of the power transformer if the meter of the tube tester is to register correctly. Therefore, a variable resistor is connected in series with the power input leads so that the voltage applied to the primary may be adjusted to the correct value. A special switch (the line-adjustment switch) connects the meter to an appropriate circuit that permits a visual determination of the correct setting of the line-adjustment control.

This line voltage should be adjusted after the filament switch is in the correct position and the tube is in the test socket. Some tubes draw a high filament current and would load down the operating voltage of the equipment if the line was adjusted first. The tube tester is designed to accurately test tubes under certain operating conditions, but these operating voltages must be accurate to accomplish this purpose. Correct line voltage adjustments will result in the required operating voltages.

SHORT CIRCUIT TEST.—The short circuit test is used to determine if there is a short between any two elements within the tube. The SHORTS switch connects the various elements of the tube under test to a voltage source in series with a neon lamp so that it glows if there is a short between the elements.

NOISE TEST.—The noise test is similar to the short circuit test and is used to check for any intermittent disturbances that are too brief to be detected on the neon lamp. Two test leads are connected into the jacks above and below the neon lamp (across the neon lamp) and the other ends of the leads are connected to the antenna and ground of a radio receiver.

The SHORTS switch is then turned through the various positions as the tube under test is tapped gently. Any intermittent disturbances between the electrodes cause a momentary oscillation that is reproduced by the loudspeaker as noise.

RECTIFIER TEST.—Rectifier tubes and diode detector tubes can be tested only for emission; therefore, the rectifier test is quite simple. The diode or rectifier tubes are tested by first setting all the switches and potentiometers to the positions indicated on the roller chart. The tube is placed in the proper socket and the line voltage is adjusted after the tube has been allowed time to warm up. Then the designated diode or rectifier button is pushed. The meter will indicate above the rectifier mark for a good tube. If the reading is below the mark, the tube is weak or gassy. If there are two or more plates in the tube, each is tested separately.

MUTUAL-CONDUCTANCE TEST.—Mutual-conductance tests are performed on amplifier tubes by positioning the SELECTOR switches and potentiometers as indicated by the roller chart. After placing the tube in the proper socket, and adjusting the line voltage, a short circuit test should be conducted. To make the mutual-conductance test, the designated pushbutton is depressed. The meter will indicate the quality of the tube. It should be noted that to obtain accurate indications on the meter, the RANGE switch must be in the correct position. A reading lower than that given on the roller chart indicates a weak tube. A higher reading may indicate a gassy tube.

GAS TEST.—This test is used to determine whether or not there is gas present in the vacuumized envelope of the tube. It should be noted that this is NOT a test for gas filled tubes such as a thyratron. The gas test is usually made after the quality test and therefore the switches and potentiometers are in the required positions. The GAS NO. 1 button is depressed, which connects the proper grid and plate voltages. This will result in a certain indication on the meter. While GAS NO. 1 button is held down, GAS NO. 2 button is also depressed. If the tube is gassy, the meter reading will increase. If the increase is more than two divisions on the scale, the tube is not acceptable due to excessive gas.

Tube Tester Limitations

In general, tube testers do not completely indicate tube performance because they present a fixed impedance to the tube grid and plate which may or may not be that of the equipment in which the tube is to operate. Also, the tester takes no account of the interelectrode capacity of the tube. JAN specifications allow a wide deviation of interelectrode capacity which makes an accurate prediction of tube performance with a tube tester difficult. The range of operating frequency affects performance also.

It is impracticable to design a complete testing instrument that will evaluate the performance of any tube in any circuit in which it is being used. A tube may test low on the tester and yet work perfectly well in the circuit or, on the other hand, it may check good in the tester and not function in the equipment. As a rule, therefore, only dead, shorted, or extremely weak tubes should be discarded purely on the basis of a tube tester check.

Further, it is NOT advisable to replace a large number of tubes especially in high frequency circuits without checking their effect on the circuit, one tube at a time. In any complicated circuit it is bad practice to arbitrarily replace a large number of tubes. It is better to replace them either tube by tube or in small groups.

Another aid to checking new tubes is the "eyeball" check. Many new electron tubes with visible defects find their way into equipment. A quick visual inspection of all new tubes will save time by eliminating these obvious defects. Some of the things to watch for are: Crushed spacers, loose internal plate structures, bent or missing pins, broken tips and cracked glass envelopes, and unflashed getters which are indicated by no silvery deposit anywhere on the inside of the envelope.

CATHODE-RAY OSCILLOSCOPE

The cathode-ray oscilloscope is one of the most useful and versatile of test instruments. It is essentially a device for displaying graphs of rapidly changing voltages or currents, but is also capable of giving information concerning frequency values, phase differences, and voltage amplitude. It is also used to trace signals through electronic circuits to localize sources of distortion and to isolate troubles to particular stages.

The oscilloscope is an instrument consisting of a cathode-ray tube and associated circuits for use in viewing wave shapes of voltages or currents. The cathode-ray tube, which is discussed in detail in *Basic Electronics*, NavPers 10087, consists of three parts—an electron gun for supplying a stream of electrons in the form of a beam, deflection plates for changing the direction of the electron beam a small amount, and a screen covered with a material which gives off light when struck by the stream of electrons directed at it by the gun.

As shown in figure 10–7, the associated circuits include a time-base generator whose ouput is amplified by the horizontal amplifier. This output is applied to the horizontal deflection plates causing the electron beam to move from the left to the right side of the screen at a uniform rate. Then the beam returns hurriedly to the left side where it begins another sweep across the screen. This action is accomplished by generating a voltage that rises at a uniform rate to a certain value and then quickly drops to its starting value. A wave shape such as this is called a saw-tooth wave.

A saw-tooth voltage wave is applied to the horizontal deflection plates, where it causes the electron stream to change direction. Since negative voltages repel and positive voltages attract electrons, the gradual rise in voltages causes the left plate to become increasingly negative and the right plate increasingly positive, and thereby causes the spot to move across the screen. The quick drop of the voltage to its start-

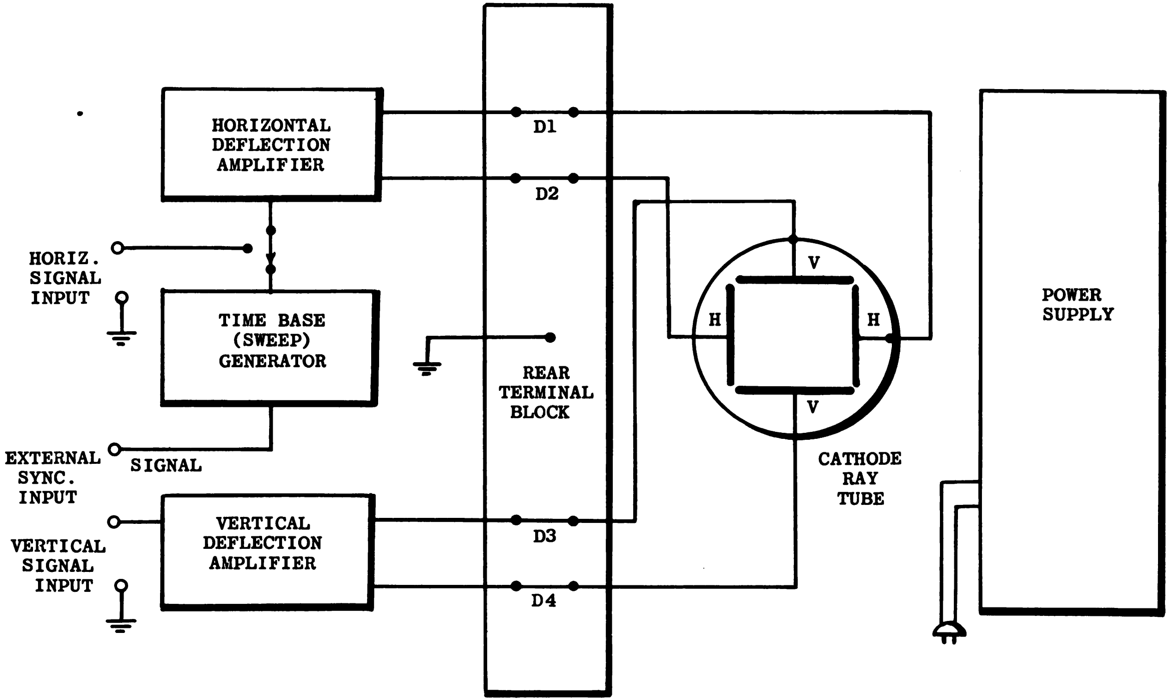


Figure 10–7.—Block diagram of cathode-ray oscilloscope.

ing value returns the spot from right to left in a very short time. This is called the flyback time.

The saw-tooth voltage is normally generated by the time-base generator, and applied to the horizontal deflection amplifier. Should some other external voltage for horizontal deflection be desired, it is applied to the terminals marked horizontal signal input. The waveform fed to the horizontal deflection amplifier is increased in amplitude to that needed for a trace of the desired length and applied to the horizontal deflection plates.

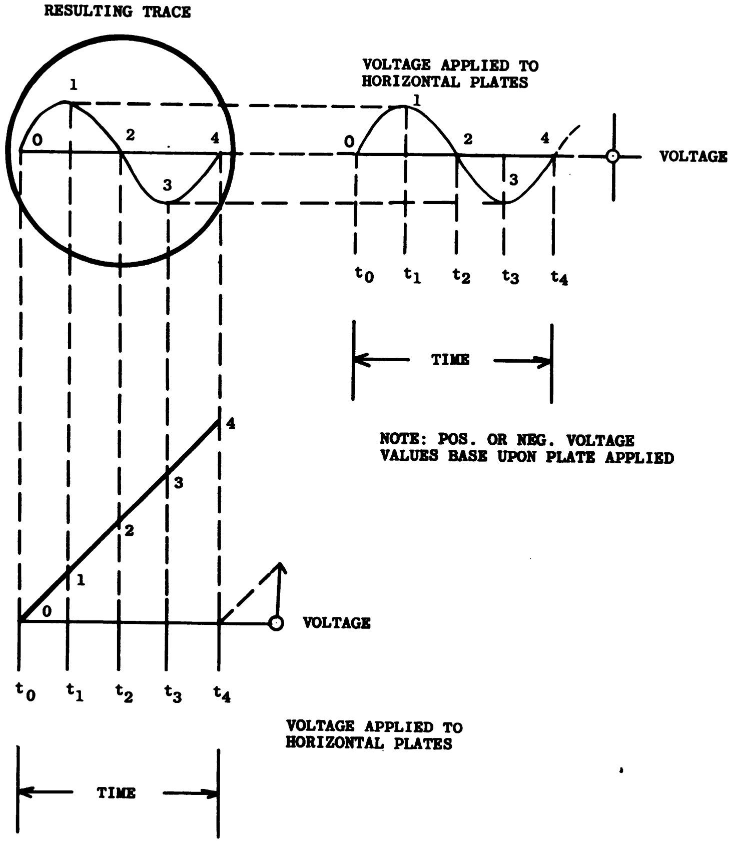

RESULTING TRACE
VOLTAGE APPLIED TO HORIZONTAL PLATES
0
1
2
3
4
VOLTAGE
t0 t1 t2 t3 t4
TIME
NOTE: POS. OR NEG. VOLTAGE VALUES BASE UPON PLATE APPLIED
0
1
2
3
4
VOLTAGE
t0 t1 t2 t3 t4
VOLTAGE APPLIED TO HORIZONTAL PLATES
TIME

Figure 10–8.—Development of sine wave on face of oscilloscope.

Signals applied to the vertical signal input terminals are amplified by the vertical deflection amplifier and applied to the vertical deflection plates.

By studying figure 10–8 you can see the results of how a sine wave is reproduced on the screen when a saw-tooth voltage is applied to the horizontal plates and a sine wave voltage is applied to the vertical plates. The saw-tooth, which represents time, is divided into segments numbered t_0 to t_4. The input sine wave also has the same divisions to show the instantaneous voltage amplitude at these same points. The resultant is a single cycle of sine wave on the screen.

Your ability to properly operate an oscilloscope will not only help you perform your duties as an AQ3, but will provide a means of visually illustrating the operation of various electrical circuits to be studied as you advance in rate.

A picture of a typical cathode-ray oscilloscope is shown in figure 10–9. A description of the operating controls and their function is as follows:

FRONT PANEL CONTROLS:—

INT-OFF—operates the power off-on switch and controls the intensity or brightness of the image on the screen.

FOCUS—adjusts the focus or sharpness of the trace on the cathode-ray tube.

HOR. and VERT. POS. (left-right, down-up)—used to adjust the position of the trace on the screen, either horizontally or vertically.

HORIZONTAL AMP. PANEL:—

HOR. ATTEN.—selects the source of signal, a. c. with attenuation, sweep, or d. c. The signal is then fed to the horizontal amplifier.

HOR. GAIN—controls the gain of the horizontal amplifier.

DC—connection for d-c input to the horizontal amplifier.

AC—connection for a-c input to the horizontal amplifier.

GND—connection for ground when using either a-c or d-c inputs to the vertical amplifier.

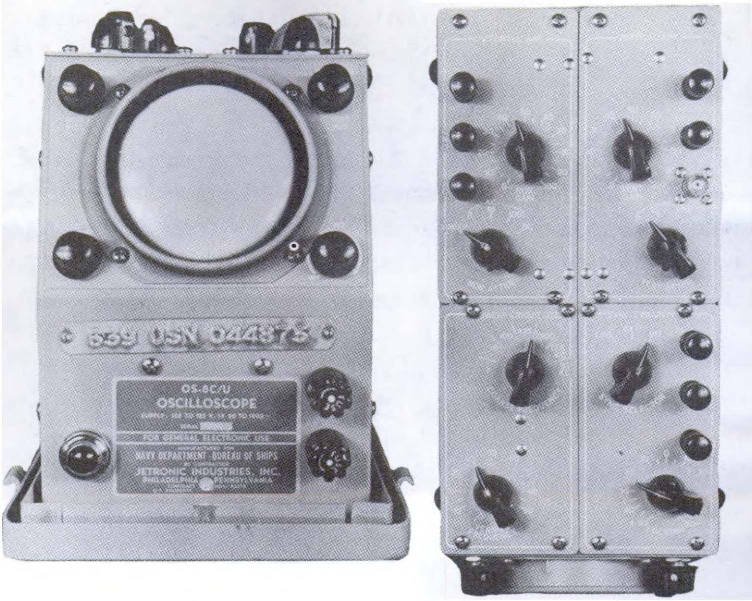

639 USN 044873
OS-8C/U
OSCILLOSCOPE
FOR GENERAL ELECTRONIC USE
NAVY DEPARTMENT · BUREAU OF SHIPS
JETRONIC INDUSTRIES, INC.
PHILADELPHIA PENNSYLVANIA
COARSE FREQUENCY
SYNC. SELECTOR

Figure 10–9.—General-purpose oscilloscope OS–8C/U.

SWEEP CIRCUIT OSC. PANEL:—

COURSE FREQUENCY—provides a course adjustment of the sweep frequency.

VERNIER FREQUENCY—provides a fine or vernier adjustment of the sweep frequency.

SYNC. CIRCUIT PANEL:—

SYNC. SELECTOR—provides for the selection of the synchronizing voltage source as follows:

LINE—signal is taken from input to power supply.

EXT.—signal is supplied by an external source connected to the EXT. terminal.

INT.—signal is taken from the input to the vertical amplifier.

LOCKING—selects the polarity and amplitude of the synchronizing voltage applied to the sweep circuit oscillator.

EXT.—input for external synchronizing voltage.

Z AXIS—connection for external voltage to be used in intensity modulation of the electron beam.

LINE—an external source of line supply frequency.

VERTICAL AMP. PANEL:—

VERT. ATTEN.—provides for attenuation of a-c signals or d-c input without attenuation.

VERT. GAIN—controls the gain of the vertical amplifier.

DC—connection for d-c input to the vertical amplifier.

AC—connection for a-c input to the vertical amplifier.

GND—connection for ground when using either a-c or d-c inputs to the vertical amplifier.

OPERATION.—The operation of the OS–8C/U cathode-ray oscilloscope for observation of waveforms is relatively easy, in that the signal to be observed is applied to the a-c terminal of the vertical amplifier and that the horizontal sweep frequency need only be synchronized with it. The steps for operating the OS–8C/U are listed below:

1. The signal to be observed is connected to the a-c input terminal of the vertical amplifier, and the ground connection of the input signal is connected to the GND terminal.
2. The INT-OFF control is turned clockwise to switch the power on. After the oscilloscope has warmed up, adjust the brightness or intensity of the trace to a comfortable level.
3. Set the COURSE FREQUENCY control to the lowest frequency.
4. Set the SYNC. SELECTOR switch to the INT. position.
5. Set the VERT. GAIN and the VERT. ATTEN. controls for suitable deflection.
6. Set the HOR. GAIN control for desired pattern width.
7. Slowly rotate the VERNIER FREQUENCY control until the desired pattern appears and is steady.
8. If the number of cycles is too great, the COURSE FREQUENCY control is adjusted a step higher until the desired number of cycles appear and are steady. This may require readjustment of the VERNIER FREQUENCY control.
9. The trace can then be locked in synchronization by adjusting the LOCKING control, either positive or negative, until the pattern appears steady and fixed.

When it is desired to use an external synchronizing voltage, it can be connected into the EXT. synchronization terminal. The SYNC. SELECTOR must be turned to EXT. The other controls are adjusted as above. When it is desired to use line voltage for synchronization, the SYNC. SELECTOR is turned to LINE and the other controls are adjusted as above.

MOTORS AND GENERATORS

The rotating machinery found in aviation fire control equipment will vary in both size and type. A few examples of these variations are given below:

1. 115-volt, 400-cycle, 3-phase, ¼-horsepower antenna drive motor.
2. Small series wound d-c gyro drive motor.
3. Compound wound d-c spin motor.
4. 28-volt d-c constant speed motor.
5. A-c induction motor driving a split field generator supplying a-c power to a free gyro.
6. Split field armature servomotor driving a d-c tachometer user as a d-c generator.
7. A 2-phase, permanent-magnet type alternator which generates a 2-phase reference voltage.

From this list, it is apparent that the AQ will be concerned with rotating machinery. The theory and operation of motors and generators is thoroughly discussed in *Basic Electricity*. In this section our main interest is the maintenance required in the upkeep of these rotating machines.

Disassembly

In the maintenance of motors and generators, knowledge of the disassembly (and assembly) is of importance. Because there exist many different physical arrangements of these devices, it is not feasible or desirable to cover all disassembly techniques. Instead, let us consider the disassembly of a typical motor shown in figure 10–10. This figure will also serve to identify the nomenclature of the various parts.

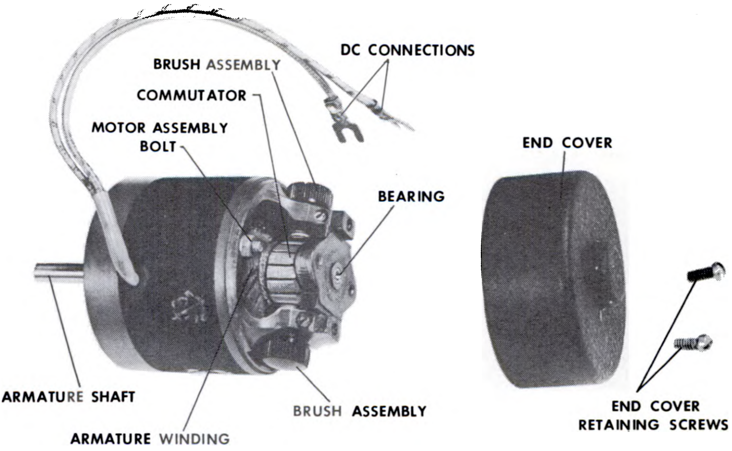


Figure 10–10.—D-c motor.

In disassembling this motor, the end cover is removed after removing the two screws that fasten it to the frame. This exposes the frame, bearing, brush assembly, commutator, and a portion of the armature. The brushes may be removed by unscrewing the brush holder cap, withdrawing the spring, and then the brush. The field connections may be unsoldered or disconnected at the brush holder assembly for testing. In most units removal of brushes will provide the desired test points. This degree of disassembly will permit cleaning, lubrication, testing, and brush replacement. However, it is possible to further disassemble the motor by removing the motor assembly bolts, and then remove the armature and perhaps the field coils. This further degree of disassembly is usually reserved for overhaul and repair units.

Inspecting and Cleaning

Rotating machinery should be inspected and cleaned at prescribed intervals (periodic checks) and whenever repairs to the machinery have been made. For such cleaning and inspection, the following procedure is suggested:

1. Unfasten and remove end cover.

2. Remove any dust and dirt from machine and end covers, using clean, dry, compressed air or a soft brush.

3. Loosen, gently remove, and inspect brushes, being extremely careful not to nick or mar edges of brush. Note the location and position from which each is removed so that it can later be replaced in exactly the same position.

4. Check commutators or sliprings for excessive wear, pitting, dirt, thrown solder, or other defects. A highly polished commutator or slipring is desirable, but a dark-colored one should not be mistaken for a burned one. If the surface is dirty, clean with a lint free cloth moistened in a cleaning solution (Specification PS–661) and wipe dry. Avoid fingermarking the commutator or slipring surface.

5. Secure all brushes in their holders, making certain they are replaced in exactly the position from which they were removed.

6. Replace and secure end covers.

SLIPRINGS.—Sliprings are solid metal rings mounted on the rotor of alternating current machines for transferring the power to or from external circuits through brushes or wipers. Sliprings are also used on synchros, radar antenna unit connections, and turret connections. Sliprings are usualy made of copper, bronze, or other nonferrous metals, although iron and steel have been used.

While they vary in size and type, the maintenance of sliprings is essentially the same for all types. They should be inspected periodically for wear, grooving, and cleanliness. Normally, the surface of the rings should be bright and smooth.

As mentioned previously, the connection to the rings is by brushes or wipers. Wiper contacts are used with devices that do not require high current and consequently require only light pressure when making contact. Excessive pressure will result in excessive wiper wear, because the wiper contact is usually of a softer material than the rings. Any contacts showing considerable wear should be replaced.

If sliprings are inspected and found rough, scratched, or grooved, corrective action must be taken. They can be smoothed with a fine crocus cloth or sandpaper. However, care should be exercised not to cause high and low spots which will interfere with high-speed operation. Further repairs, such as cutting with a lathe, should be performed at overhaul activities. Also in cleaning with a solvent, be careful not to allow the solvent to enter the bearings since the solvent will cut oil or grease. This, of course, will cause the lubricant to flow out of the bearing.

COMMUTATORS.—Commutators have been called the "soft spot" of d-c machinery because they require considerable maintenance. Unlike the slipring, the commutator is a series of copper segments separated by an insulator. When the brushes make contact with a pair of segments, an armature coil is connected into the circuit. Thus when the motor or generator is moving, the brushes and commutator switch coils in and out in the proper sequence.

The normal appearance of the commutator is a shiny, smoothly worn, chocolate brown color. A blackened or pitted commutator is caused by poor brush and segment contact, open or shorted coils, overloads, etc. If the brushes are causing the blackened appearance, they should be replaced and then the commutator should be cleaned. Cleaning is accomplished by the use of fine sandpaper and the recommended solvent. The sandpaper should be held against the commutator by a piece of wood that is grooved to fit the commutator. NEVER USE EMERY CLOTH. Emery is an electrical conductor, which will cause a short circuit.

If the fault is other than brush and segment contact, that is a short or open coil, the machine should be replaced and sent to overhaul. Another fairly common defect is HIGH MICA. As the copper of the commutator wears down, the mica, which is the insulation separating the segments, does not. Consequently, it may be higher than the segments. The high mica gives a bounce to the brush every time it passes underneath; this results in arcing because the brush is constantly breaking contact. High mica can be spotted by rubbing your fingernail over the surface of the commutator. There should be a small depression between each segment. If there is high mica, this depression disappears. Undercutting is the remedy for high mica, and this operation is normally reserved for the overhaul activities.

BRUSHES.—Brushes are found in numerous sizes and shapes and are made of various materials and compounds. Many brushes used in aircraft equipment are made of a composition of graphite and other forms of carbon. In all probability, the majority of the maintenance you, as an AQ, will perform on rotating machinery will be concerned with brushes. Brushes should be checked for wear, chipping, oil soaking, sticking in the brush holders, spring tension, length, and area of contact with the commutator. If for any reason a brush is removed and is to be replaced, they should be marked or tagged so they may be replaced in the same brush holder in the same position they occupied before removal.

Brushes that show excessive or improper wear, chipping, or are oil soaked should be replaced. Care should be exercised in obtaining the CORRECT replacement. Consult the maintenance manuals. Brushes in aircraft equipment wear away rapidly, especially when the aircraft is operating at high altitude. It is therefore important that the brushes be changed before they are completely worn away in order to prevent DAMAGE to the equipment in which they are used.

In order that the technician can tell when replacement is necessary a brush marking system has been developed. Brushes are marked to indicate allowable wear by a readily noticeable groove in their edge. This groove extends from the top of the brush down to a point of 75 percent of the brush wearing depth. (The top is the end opposite the wearing face.) Thus if the brush is worn down to the groove, it must be replaced. If no groove is present, consult the equipment handbook for acceptable minimum brush lengths.

Brush wear is especially rapid at high altitude (40,000 ft.). This rapid brush erosion is the result of the lack of moisture content in the air at these altitudes. The moisture serves to promote a conducting oxide film between brush and the sliprings or commutator; this film prolongs brush life. Because of this rapid wearing, brushes used in high altitude aircraft should be checked more often and very carefully.

In the replacement of brushes, you will find that some new brushes are ready for use. That is, the brush face is slightly concave so that it fits tightly on the commutator. However, because other new brushes are NOT ready for use, they must be sanded in. This sanding, or seating, can be accomplished by wrapping fine sandpaper around the commutator. The paper is placed sand side up with a lap following the direction of normal rotation of the device, and is held in place by a rubber band. Do NOT use glue or tape. The brushes are placed in their holder under spring tension, and the armature is rotated slowly by hand in the direction of normal rotation. In so doing, the contact surfaces of the brushes are sanded until their curved surfaces match the curvature of the commutator. The carbon dust from the brushes must be removed from the device by using dry compressed air followed by cleaning with safety solvent.

Lubrication

Bearings and actuators are the prime lubrication considerations for motors and generators. Antifriction bearings are either ball or roller bearings. These, especially ball bearings, are widely used in aircraft rotating electrical machinery. Extensive use is also made of sealed bearing assemblies. These make maintenance and lubrication very easy since sealed bearings are prelubricated and require almost no attention during normal operation of the machine in which they are installed. However, never assume a motor or generator is of the prelubricated type, check the maintenance manual.

For the proper maintenance and lubrication of ball bearings, the detailed recommendations of the manufacturer as given in the *Handbook of Service Instructions* should always be followed. In the inspection of ball bearings, the assembly is slowly rotated. Bearings showing pronounced stickiness or bumpy operation should be replaced. The bearings are also inspected the cracks, rough or pitted surfaces, and damaged balls.

Ball bearings may be cleaned and relubricated as follows:

1. Wipe the outside of the bearings clean, using a clean cloth.
2. Wash the bearings thoroughly in cleaning solution (Specification PS-661).
3. Blow the bearings with compressed air until dry. The bearings should not be rotated while washing or drying.
4. Relubricate by packing the bearing one-fourth to one third full with the prescribed lubricant.
5. Wipe off any excess lubricant.

Excessive lubrication leads to bearing trouble, and andue amount of grease in the slipring or commutator compartment of the machine may result. Brush and slipring wear increases appreciably if a large amount of lubricant is present. Further, a large amount of lubricant may result in "soaking" of the brushes; also it may mix with the carbon dust from the brushes which can short out the segments of the commutator. Insufficient lubrication will, of course result in wear, heating, and the possible stoppage of the bearing.

Listed below are the specification numbers and applications for recommended lubricants used on fractional horsepower actuating motors and drives. Further details (including stock numbers) on lubricants for naval aircraft and accessories are found in *Technical Note* No. 31-53.

Applications	*Specifications*
Ball bearings, gears	MIL-G-3278 Grease.
Armature bearings	MIL-G-3278 or MIL-L-7711 Grease.
Clutch disks	MIL-G-7181 Graphite grease.
Sleeve bearings	MIL-L-7870 or MIL-L-644 Oil.
Actuator screws	MIL-G-7118 Grease.
Oilers	MIL-L-7870 or MIL-L-644 Oil.

Motors and generators must be lubricated after certain periods of operation; therefore their lubrication is usually included in the aircraft's or engine's periodic checks. However, there are some equipments that require lubrication only every three months, six months, or yearly. These types of equipments must have the dates of each lubrication logged in the equipment card or logbook, so that the date of the last lubrication can be found and the date for the next lubrication can be computed.

Testing

Motors and generators are tested periodically as part of the preventive maintenance schedule and occasionally when locating a malfunction during corrective maintenance. There also exists various degrees of testing which may be grouped into three descriptive categories; namely, field testing, maintenance shop testing, and overhaul testing. There are no hard and fast rules restricting a certain test to any one of the three categories. The degree of testing will fluctuate with such variables as the testing equipment available, the ability and experience of personnel, the needs of the service, and the policies of operating activities. Naturally, the more complicated tests and extensive repairs will probably be accomplished only at overhaul activities. Bearing in mind these variables, let us now consider some of the tests.

REPLACEMENT.—Usually one of the simplest and surest tests is replacement. If the replacement operates satisfactorily, the original device is subjected to further test. If the replacement does NOT operate satisfactorily, the load or power source needs investigation.

Trouble in the gears or actuating devices often causes the failure of a motor to operate. Check the unit driven by the motor for failure of the mechanism or drive. If the motor has failed as a result of a failure in the driven unit, you must correct the fault before completing the installation of a new motor.

If the driven unit is functioning, check the external electrical circuit for loose or dirty connections and for improper connection of wiring. Look for open circuits, grounds and shorts by following the circuit testing procedure discussed previously. If the fuse is not blown, failure of the motor to operate is usually due to an open circuit. A blown fuse usually indicates an accidental ground or short circuit. The chattering of the relay switch which controls the motor is often caused by a low battery. When the battery is low, the open circuit voltage of the battery is sufficient to close the relay, but with the heavy current draw of the motor, the voltage drops below the level required to hold the relay closed, and the relay opens. When this occurs, the voltage in the battery increases enough to close the relay again. This cycle repeats and causes chattering. Chattering is very harmful to the relay switch as the heavy current causes an arc which will burn the contacts.

If the machine is a generator, a reverse procedure is followed. That is, check to see that the generator is driven properly. If it is, then check the output circuit for opens, grounds, and shorts.

If you determine the fault is the machine itself, the procedure discussed under "Inspecting and Cleaning" should be followed. After cleaning, the device should be lubricated. If the machine still fails to operate, further tests are required.

FIELD COIL TESTS.—Field coils may be tested by partially disassembling the machine—the brushes must be removed. The field coil should be tested for opens, grounds, and shorts between windings. A continuity test is used to check for open coil windings. An ohmmeter or megger should be used for the continuity test as some resistance should be present.

The ohmmeter can then be used to check for grounds, or the megger can be used to check for grounds or insulation breakdown. A comparison of the resistance in the different coils will indicate any shorts between windings.

Another test that may be used to check for opens, shorts between turns of the field coil winding, or increased resistance of the coil is made with a voltmeter. This test is shown in figure 10–11. A battery is applied to the series connected field coils and the voltage drop across each coil is measured. If the entire battery voltage is read across the field coil, the coil must be open. If the voltage drop across one coil is substantially lower than across the other coils, there is probably a short between several turns of the coil. If the voltage drop is substantially higher, the coil has increased in resistance.

ARMATURE TESTS.—The armature coils must be tested for the same defects as the field coils. However because of the lower resistance, the tests are more difficult. Since the connections to the armature coils are made through the commutator, the test should be made at this point. Care should be exercised not to damage or mar the finish of the commutator with sharp probes.

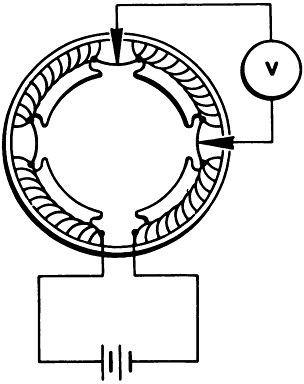


Figure 10-11.—Test procedure using a voltmeter.

The ground test is made with a megger connected from the shaft to each commutator segment. Thus the resistance of each coil to shaft is measured. A high resistance is normally read; a grounded coil will give a zero megger reading. Partial grounds may give readings in the thousands of ohms.

An open or short can be detected by using the arrangement in figure 10–12. The variable resistance should be adjusted to half-scale meter reading. As the armature is rotated, a high meter reading indicates an open coil across the particular segments. A low reading indicates a shorted coil.

Another method of testing an armature for shorts and opens is shown in figure 10–13. This method employs the use of a growler. When the armature is placed in the growler, it completes the magnetic circuit; its windings acting as the secondary of a transformer, with the growler coil forming the primary.

Shorts are checked by placing a thin strip of iron or steel

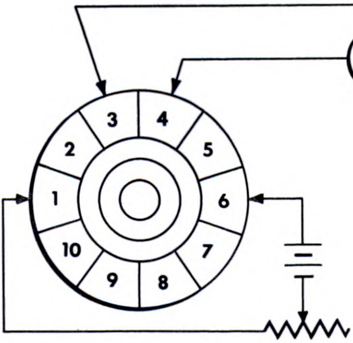


Figure 10–12.—Voltmeter test for shorts and opens.

on a core segment as shown. If the associated coil is normal, there will be no attraction for the strip of metal. Where a short circuit exists, the strip of metal will flutter. By rotating the armature, each segment and therefore each coil can be tested.

Opens are checked with a growler by shorting each pair of adjacent commutator segments with the strip of metal. If the coil is normal, the same amount of flashing will occur at each segment. If an open exists, a heavy flash will occur. Incidentally, smoke rising from the armature immediately

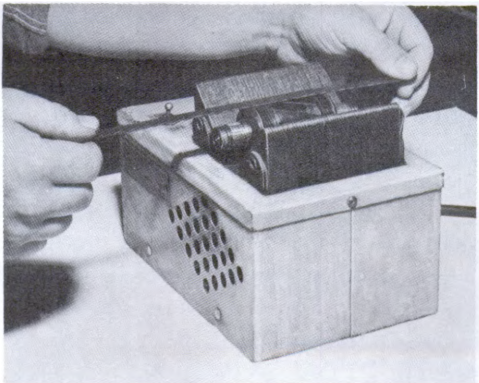


Figure 10–13.—Checking an armature with a growler.

indicates faulty insulation. It should be pointed out that the armature and field coil are tested to determine whether or not they are faulty. As an AQ, you will not be required to repair or rewind them.

TROUBLESHOOTING POINTERS

The materials used in Navy electronic equipment are considered to be the best obtainable for the purpose involved. The equipment has been carefully inspected and adjusted at the factory in order to reduce maintenance to a minimum. However, a certain amount of checking and servicing will always be necessary if armament equipment is to be kept in efficient and dependable operation. The Aviation Fire Control Technician is concerned with such checking and servicing. A large part of his activity is devoted to preventing equipment failure by detecting defective operation and component deterioration in the early stages. This is accomplished by routine inspections of the equipment.

When defective parts or unsatisfactory operation have been revealed in any of the inspections, it is necessary to analyze the equipment, find the defective component or part, and make the appropriate replacement or repair. In general, the most effective procedure for this analysis is shown in figure 10–14.

STEP 1.—Try to locate the trouble by observing the system's faulty operation. This may mean applying an input signal, some physical movement of the system's parts, or other means of activating operation. The system should then be carefully studied to determine any probable cause of faulty operation. Faulty operation is considered to be any reduction of performance below the specifications established for a particular equipment. It should be noted that the terminology, faulty operation, is NOT reserved for the condition where the equipment will not operate at all.

STEP 2.—A visual check provides the logical second step in arriving at a defective component. In this stage of servicing, the equipment is inspected for broken leads, parts which are burned or smoking, controls which are not functioning normally, resistors which smell hot or which feel abnormally

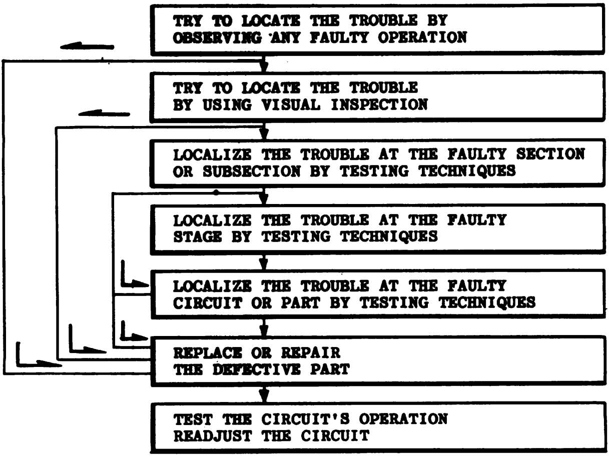

TRY TO LOCATE THE TROUBLE BY OBSERVING ANY FAULTY OPERATION
TRY TO LOCATE THE TROUBLE BY USING VISUAL INSPECTION
LOCALIZE THE TROUBLE AT THE FAULTY SECTION OR SUBSECTION BY TESTING TECHNIQUES
LOCALIZE THE TROUBLE AT THE FAULTY STAGE BY TESTING TECHNIQUES
LOCALIZE THE TROUBLE AT THE FAULTY CIRCUIT OR PART BY TESTING TECHNIQUES
REPLACE OR REPAIR THE DEFECTIVE PART
TEST THE CIRCUIT'S OPERATION READJUST THE CIRCUIT

Figure 10–14.—Troubleshooting procedure.

hot to the touch, tubes which are dark when the equipment is turned on, loose fastenings, and any other indications of failure.

In troubleshooting some aircraft fire control equipment, such as bomb directors, fire control radars, and others, the initial operating check is made by observing the front panel meters which aid in localizing difficulties. Of course, you have to know the normal readings of these meters to perform this check. A log or the maintenance manual will give you these normal readings.

In the preliminary check, the experience of the technician is an important factor, and the knowledge gained from previous difficulties with the device often serves as a guide in knowing what to expect. Both the experienced and the inexperienced can find assistance in preliminary checking by consulting the instruction manuals for the specific equipment involved, since these often give detailed procedures for making the initial inspections. However, many electrical faults do not result in symptoms which can be detected visibly and it is frequently necessary to resort to other methods of detecting failures.

Steps 3, 4, 5.—Troubleshooting steps 3, 4, and 5 consist of localizing the trouble to the faulty part. The degree of maintenance entailed in these three steps will vary with equipment, experience, and activity. The testing techniques will also vary. In some situations the faulty component can be isolated by means of an ohmmeter, a voltmeter, or a tube tester. Other situations will require more advanced test equipment and techniques, such as signal tracing and the use of the oscilloscope.

STEP 6.—This entials the replacement or repair of the defective part. You know that *all* replacements or repairs should duplicate the defective part. In an emergency two resistors or two capacitors properly connected may be used to duplicate the value of the defected part. However, such substitutes are always temporary. The permanent replacement should be made as soon as the correct parts are available. Remember, permanent replacements are always exact duplicates.

STEP 7.—Test the circuit operation: Readjust the circuit if necessary. After you make either temporary or permanent repairs, ALWAYS TEST THE EQUIPMENT. Use the operational tests given in the maintenance and service manuals. They will contain the information telling you what adjustments are required and how to make the adjustments.

As an Aviation Fire Control Technician 3, you will not be required to complete this troubleshooting procedure on all equipments. The reason for this is the vast difference in complexity of the equipment maintained by the AQ. Isolating a faulty part in a noncomputing sight is much different than isolating a faulty part in missile control radar. As you progress in the field, your ability to satisfy the needs at advanced maintenance levels will increase.

TUBE TESTING.—Care should be used in tube testing while troubleshooting. One result of a recent study is the conclusion that maintenance affects both the quantities of tubes used and the reliability of electronic equipment. Not only are some individual circuits difficult to analyze, but the interdependency of associated circuits presents problems that make the diagnosis of equipment trouble difficult. As an alternative remedy, **WHOLESALE REPLACEMENT** of tubes is often attempted.

The end result of this wholesale replacement is a decreased equipment reliability and an increase in the number of tubes used. This occurs because: (1) Approximately 30 percent of the tubes rejected are good, (2) a considerable number of new tubes fail on installation, (3) tube replacement often requires circuit readjustment, (4) the possibility of sockets becoming worn or broken, and (5) the masking of the true nature of the trouble.

Examples of the masking of basic troubles were also contained in the report. In one case, a tube was removed from a radar equipment because of an open cathode, and a new tube installed. The equipment was returned to service. Two days later, the unit was again in need of repair, the same socket having produced the same trouble. The tube was replaced. Next day the equipment failed again for the same reason. Eight tubes failed successively in the same socket for the same reason before it was discovered that the tube had lost its bias due to a fault in the associated circuitry.

The point to be gained is that mass tube replacement often does more harm than good. This should NOT be interpreted as an effort to discourage the testing of tubes or proper replacement of malfunctioning tubes. Checking tubes in tube testers can eliminate such undesirables as shorts, opens, defective heaters, and the like. However, the most effective way of testing tubes is in the equipment itself.

QUIZ

1. The basic meter movement in most meters is a/an
    a. eddy current movement
    b. electro magnet-moving coil
    c. permanent magnet-moving coil
    d. rotating disk
2. An ammeter is always connected
    a. parallel with the power source
    b. parallel with the circuit being measured
    c. in series with the circuit being measured
    d. either in series or parallel with the circuit being measured
3. A voltmeter is always connected
    a. in series with the circuit being tested
    b. parallel to the circuit being tested
    c. either in series or parallel with the circuit being tested
    d. in parallel for high scale readings but in series for low scale readings
4. The ohmmeter is used to measure
    a. resistance
    b. current
    c. voltage
    d. wattage
5. The ________________ would be used for continuity testing.
    a. voltmeter
    b. ammeter
    c. ohmmeter
    d. wattmeter
6. A megger is an instrument for measuring
    a. power factor of capacitors
    b. very high voltage
    c. very high current
    d. very high resistance
7. The more accurate type tube tester is the
    a. emission type
    b. dynamic mutual-conductance type
    c. transmission type
    d. static type

8. One thing the tube tester does not check is
   a. mutual conductance
   b. noise
   c. gas
   d. interelectrode capacity

9. The absence of a silvery deposit anywhere on the inside of the envelope of a vacuum tube indicates
   a. an unflashed getter
   b. a good tube
   c. the tube was not heated enough
   d. an open filament

10. Sliprings are more likely to be used on
   a. d-c machines
   b. a-c machines
   c. either a-c or d-c machines
   d. a-c—d-c motors

11. Commutators are more likely to be used on
   a. a-c machines
   b. d-c machines
   c. either d-c or a-c machines
   d. lap wound shunt a-c motors

12. High mica in the armature of a motor or generator will cause
   a. contact between armature and brushes
   b. arcing at the brushes
   c. better operation
   d. complete failure

13. One of the simplest and surest tests for a motor or generator is
   a. replacement
   b. increasing the load
   c. decreasing the load
   d. flashing the field

14. Chattering of the relay switch used to control a motor is most often caused by
   a. a low battery voltage
   b. an open coil in the relay
   c. the motor drawing too much current
   d. bad contacts on the relay

15. The first thing to do if a generator is not operating properly is
   a. check for proper lubrication
   b. see that it is driven properly
   c. check for continuity in the field coils
   d. check for shorts in the field coils

16. The last step in making repairs to electrical equipment is
    a. repairing defective part
    b. replacement of defective part
    c. an operational test
    d. making the electrical connections

17. The most effective way of testing tubes is
    a. in the equipment itself
    b. with a tube tester
    c. with a multimeter
    d. visual inspection

18. An ohmmeter ——————————— connected to a live circuit.
    a. is usually
    b. is always
    c. may be
    d. is never

19. Polarity must be observed at all times when using a/an
    a. ohmmeter
    b. a-c voltmeter
    c. d-c voltmeter
    d. megger

20. When using an ammeter or voltmeter, choose a scale that will
    a. peg the meter
    b. indicate near full scale deflection
    c. indicate midscale deflection
    d. indicate low scale deflection

21. To measure large amounts of current with an ammeter, shunts are connected
    a. in parallel with the meter movement
    b. in series with the meter movement
    c. from the meter movement to the power source
    d. from meter movement to ground

22. The sensitivity of voltmeters is given in
    a. volts per watts
    b. volts per amps
    c. ohms per volt
    d. watts per amps

CHAPTER 11

MECHANICAL MAINTENANCE

PORTABLE TOOLS

One of the qualifications for advancement to AQ3 requires you to have the ability to select and USE hand tools and small portable power tools necessary for the maintenance and repair of aviation fire control equipment. To do this properly, you need the knowledge of the types and purposes of the hand tools and small portable power tools available. The information concerning the commonly used tools is found in *Basic Hand Tool Skills*, NavPers 10085. The list of commonly used tools includes drills, files, grinders, hacksaws, etc.

As with any other manual skill, you cannot become proficient by studying a textbook. Nevertheless do not underestimate the value of the textbook, for it gives you the proper, safest, and most efficient methods for using these tools. To become proficient, you must combine the knowledge with the experience of doing. It is appropriate to emphasize the proper study method by briefly reviewing it.

To most effectively use the basic training course for a particular job, the following procedure is recommended:

1. Analyze the job you have to do to determine what specific operations are involved or what specific skills you must have.
2. Locate the specific operation in the course book.
3. Study both the text material and the illustrations of the operations required until you are sure you understand what is involved in each operation.

4. If possible, practice each operation a few times independently.
5. Recheck the order of operations in the job at hand.
6. Then do the job.

Besides the commonly used portable tools, the AQ has occasion to utilize special tools. Let us now consider some of these special tools; especially the ones used in the mechanical maintenance of aviation fire control equipment.

PINNING SUPPORT.—Pinning supports are used for pinning or drilling operations. A simple pinning support can be the type that is held steady by a vise. However, it is usually more convenient to have a self-supported pinning support as shown in figure 11–1. The support is essentially a **V**-shaped slot with a notch at the bottom.

For drilling and pinning operations, the support is always placed directly under the hole or part to be worked on. It is important to start the pin out by tapping it sharply from the SMALL end. This is done because most of the pins used to hold parts on shafts are tapered and staked. Staking

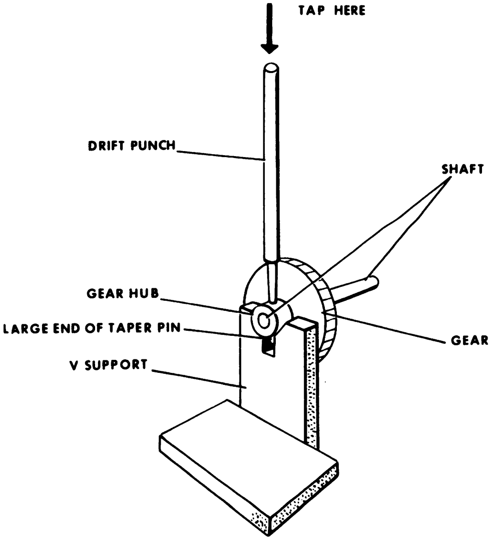


Figure 11–1.—Pinning support.

consists of driving a small amount of metal from the edge of the hole in the collar or hub over the large end of the pin. Proper technique requires the use of a light hammer and a pin punch held in a vertical position on the small end of the pin to drive it out. It is better to start the pin with a few light, sharp blows than with a heavy one which may bend or distort the parts. Once the pin is started, it should tap out easily.

Backup tools.—You will have occasion to use backup tools. Backup tools are needed to support collars and hubs for pinning whenever parts must be pinned inside a large gearing group. A backup bar is used when the part to be pinned can be reached from both sides. Two men are required for pinning when backup tools are used. The use of a backup bar is shown in figure 11–2.

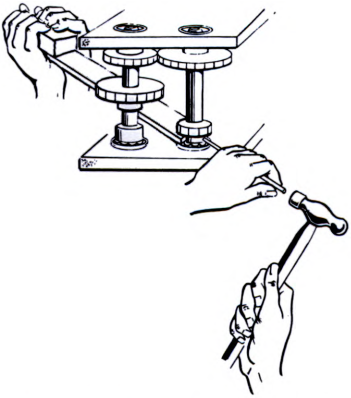


Figure 11–2.—Backup bar in use.

The main element of the backup bar is a steel bar about one foot long. A steel or lead weight is attached to one end of this bar to absorb shock. A notch, very similar to that in the pinning support, is cut in one end of this bar. When a pin is to be tapped out of a gear or collar, the pin can move down the notch. The tool is also used for supporting the gear or collar shaft whenever the pin is inserted.

Bearing punch.—A bearing punch is needed to distribute

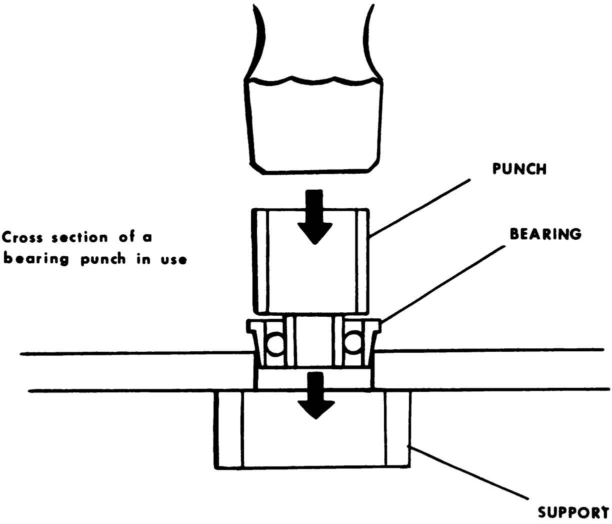


Figure 11–3.—Cross section of a bearing punch in use.

and equalize the force of the hammer blows when bearings are removed or seated. For most repair work, all that is needed for a punch is a short square-cut length of tubing. The punch size should be about 0.005 inch smaller in outside diameter than the inside diameter of the bearing hole, and must fit only on the outer race of the bearing. A bearing punch and support is shown in figure 11–3. Notice that the inside diameter of the support must be larger than the outside diameter of outer race of the bearing.

There are undoubtedly other special tools which will be required in the mechanical maintenance of aviation fire control equipment. In the use of these tools, remember to use the correct tool and to use it in the prescribed manner. When in doubt, ask the chief or other leading technicians.

BASIC MECHANICAL UNITS

While the vast majority of the equipments used in aviation fire control would be classified as electronic or electrical equipment, mechanical components are also utilized. The drive units for some computing sights, the antenna units for radars, and some computers are essentially mechanical. To understand these components and subcomponents, you need to be familiar with the basic mechanical units.

Shafts, Bearings, and Hangers

The position of a shaft often represents actual quantities such as angular or distance measurements. Because the accuracy of the equipment useing such shafts will depend upon minute movements, friction between moving parts must be held to a minimum. Shafts are therefore mounted in bearings and carefully machined parts.

A typical shaft assembly is shown in figure 11–4. The mounting plate is used to support the whole assembly inside the equipment, and the hangers are used to support individual shafts. The ball bearings on the shaft are mounted in the hanger supports. The ball bearing is constructed of three main parts—the outer race, the inner race, and balls. The outer race fits snugly into the hanger and supports the shaft and bearing assembly. The inner race fastens directly on the shaft. Then the balls are arranged to roll freely on the outer and inner race surfaces as the inner race turns with the shaft.

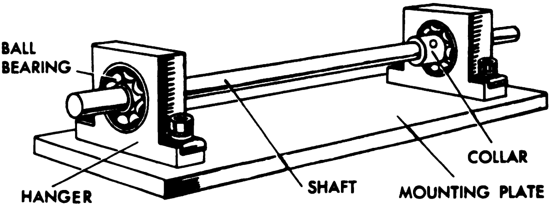


Figure 11–4.—Shaft assembly.

Notice that the hanger is secured to the mounting by screws. In our typical assembly the screw is tightened down on a lockwasher and lug plate. The lug plate prevents the lockwasher from digging into the hanger, and at the same time increases the holding surface of the screw. The machine screw is of the Allen head type, and it takes an Allen wrench to screw it in or out. However, it should be noted that this is a typical arrangement and many modifications are found in the actual equipment.

Coupling Devices

Coupling devices are used to couple shafts end-to-end. Three of the types of coupling in use are shown in figure 11–5. They are the sleeve, the universal, and the quick-disconnect.

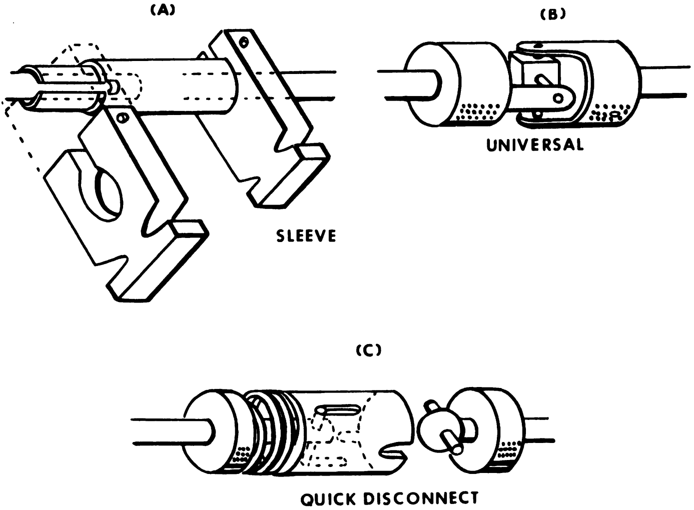


Figure 11–5.—Coupling devices.

The SLEEVE COUPLING is used to join two closely alined shafts usually where an adjustment of the shaft relationship is necessary. It consists of a sleeve over the ends of the two shafts, with a clamp over each end of the sleeve. The ends of the sleeve are slit so that the clamps can hold the sleeve tightly on the shafts. When the clamps are tight, the two shafts are held firmly together in the sleeve and will turn as one.

Notice that the clamps are tightened by a setscrew. The weight at the rear of the clamp merely offsets the weight of the screw and the overhang on the screw side. This results in an even distribution of weight, and shaft vibration is reduced. Occasionally pinning is used in place of the clamp. Pinning results in a more permanent attachment but does not permit adjustment by "slipping."

The UNIVERSAL JOINT is used to couple two shafts at an angle to each other. Because of the two pivot pins in this joint, one shaft can drive the other even though the angle between the two is as great as 25 degrees. As shown in figure 11–5 (B), the coupling device is pinned to the shafts. As the shafts rotate, the bend or angle is transferred from one pivot pin axis to the other; thus, the shafts can rotate through 360 degrees.

The QUICK-DISCONNECT COUPLING is used when it is regularly necessary to easily remove a subassembly for lubrication or alinement. A typical quick-disconnect coupling is shown in figure 11–5 (C). The male or pinned shaft fits into the opened slots of the sleeve. The sleeve is held to its shaft and kept from slipping by the pin through the shaft and the closed slot in the sleeve. The spring holds the sleeve in place thereby completing the coupling. To disconnect the shafts the sleeve is merely pushed back, compressing the spring. Thus the shafts are disconnected. To reconnect the shafts, the spring is allowed to push the sleeve out, and the pinned shaft is mated to the open slots of the sleeve.

Gears and Gear Ratios

Gears are wheels with mating teeth cut in them so that one can turn the other without slippage. When two shafts are not lying in the same straight line, but are parallel, motion can be transmitted from one to the other by means of SPUR GEARS. (See fig. 11–6.) When the mating teeth are cut so that they are parallel to the axis of rotation, the gears are called straight spur gears. Spur gears are fastened to shafts in two principal ways: One by a pin through the shaft and gear hub, and the other by a clamp tightened on the gear hub. The gear hub, in the latter case, is slit like the sleeve coupling. The advantage of the clamp method is that the gear can be adjusted by loosening the clamp and slipping the gear backward or forward on the shaft.

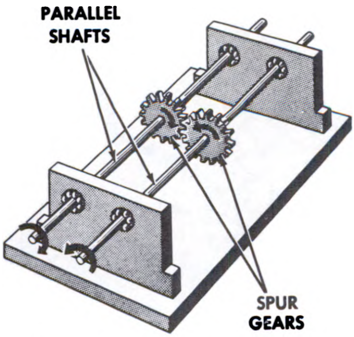


Figure 11–6.—Coupling parallel shafts.

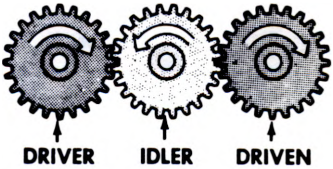


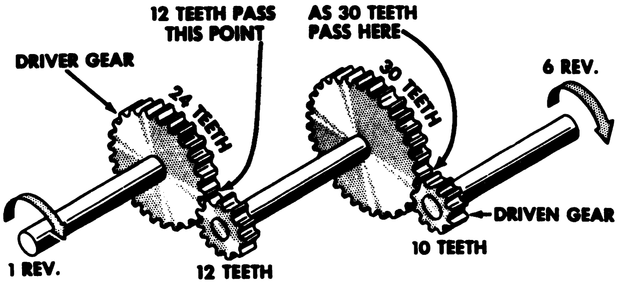
Figure 11–7.—Gear train.

If two gears are of different sizes, the smaller one is usually called a PINION. When a gear and a pinion mesh together, their shafts turn at different speeds. Notice in figure 11–6 the gears rotate in opposite directions. If it is desired to have both shafts turn in the same direction, another gear is used. This gear, as shown in figure 11–7, is called an IDLER GEAR and its only function is to reverse the driven gear rotation.

GEAR RATIOS.—The ratio between the number of teeth on the driving gear and the number of teeth on the driven gear is called the gear ratio. Since it is comparatively easy to count gear teeth, this is perhaps the simplest way to establish the gear ratio. Suppose that a gear has twice as many teeth as its pinion. For instance, the gear has 24 teeth and the pinion 12. If the gear is driving, one revolution of the gear will turn the pinion two revolutions. The pinion will turn TWO revolutions for every ONE revolution of the gear. The ratio is 2:1.

Consider for a moment the step-up ratio in figure 11–8. The driver gear turns the first small gear (ratio 2:1). The larger gear on that shaft, turning at the same speed as the small gear, turns the driven gear (ratio 3:1). The combined ratio $\frac{2}{1} \times \frac{3}{1}$ gives a stepped-up speed of 6:1.

TYPES OF GEARS.—So far we have considered only spur gears. Figure 11–9 shows some of the other gears encoun-



$$\frac{24}{12} \times \frac{30}{10} = \frac{6}{1}$$

Figure 11–8.—Step-up gear train.

tered. In the helical spur gears the teeth are cut slantwise across the face of the gear. One end of a tooth, therefore, lies ahead of the other. That is, each tooth has a leading end and a trailing end.

In straight tooth spur gears, the whole width of the face of the gear comes into contact at one time. But in the helical (spiral) gears, contact between two teeth starts first at the leading end of each tooth and moves progressively across the face of the gear until the trailing ends of the teeth are in contact. Because of the slant cut of the teeth, more than one tooth is in mesh at a time. This kind of meshing action

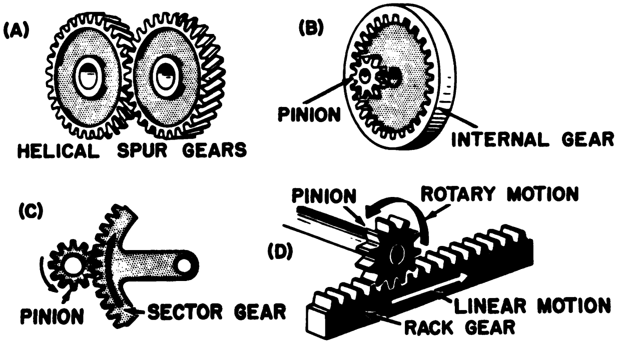


Figure 11–9.—Gear types.

keeps the gears smoothly in contact with one another, resulting in smoother and quieter operation.

The INTERNAL GEAR has teeth on the inside of a ring, pointing inward toward the axis of rotation. (See fig. 11–9.) An internal gear is always meshed with an external gear, or pinion, whose center is offset from the center of the internal gear. Either the internal or pinion gear can be the driver gear, and the gear ratio is calculated the same as for other gears—by counting teeth.

Occasionally only a portion of a gear is needed where the motion of the pinion is limited. In this case the SECTOR GEAR (fig. 11–9) is used to save space and weight; and as you know space and weight are at a premium in aircraft. Notice that the sector gear is simply part of a gear.

Another type shown in figure 11–9 is the RACK GEAR which is used for the conversion between rotary and linear motion. A rack is simply a straight bar with gear teeth cut on it. When a gear positions another gear, it is transmitting rotary motion. However, when a gear positions a rack, it is converting rotary motion into linear motion. When the gear turns, the rack moves along its guide rails. The rack can also drive the gear. As the rack moves along, it turns the gear. The rack transmits values by its position, just like shafts and gears. Its position is the linear distance it has moved from its zero position.

Although not a gear, it is instructive to note at this time another device for converting rotary to linear motion. This is the SCREW and TRAVELING BLOCK, or NUT. (See fig. 11–10.) As the screw is turned, the block is threaded along the screw. Note that the block is prevented from turning by the rod.

The distance the block travels for each turn of the screw depends upon the lead of the screw thread. The lead is the distance between spirals of a thread. A small lead will move the block a short distance. A large lead will move the block a large distance. The distance the follower block travels for one turn of the screw is always equal to the lead, that is, the distance between corresponding points on the same thread, no matter how many threads there are.

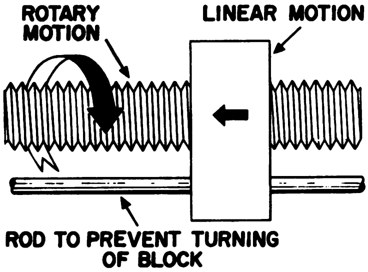


Figure 11–10.—Screw and traveling block.

BEVEL GEARS.—Bevel gears are used to transmit motion between shafts at almost any angle to one another. This is because bevel gears can be designed to suit the angle between any two shafts. If a pair of bevel gears are of equal size and their shafts are at right angles, they are called MITER gears. Notice in figure 11–11 that the faces of the miter gears are beveled at a 45-degree angle.

If the gears are cut at any angle other than 45 degrees, they are considered and called bevel gears. The gears shown in figure 11–11 are called STRAIGHT bevel gears, because the whole width of each tooth comes in contact with the mating tooth at the same time. However, you will also encounter SPIRAL bevel gears with teeth cut so as to have advanced and trailing ends. They have the same advantages as other spiral (helical) gears—less lost motion and smoother, quieter operation. The gear ratios for bevels are found in the same way as for spur gears, by counting the teeth on each gear.

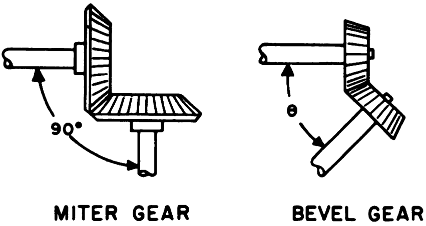


Figure 11–11.—Bevel gears.

Worm and Worm Wheel

The worm and worm wheel are a combination of a screw and gear. The worm is a screw with a thread of special shape. As shown in figure 11–12, worm gears have many uses and advantages.

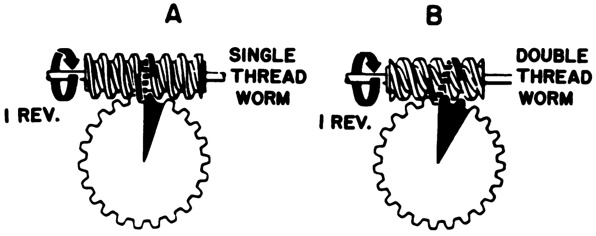


Figure 11–12.—Worm gears.

Part (A) of figure 11–12 shows the action of a single thread worm. For each revolution of the worm, the worm wheel turns one tooth. Thus if the worm wheel has 25 teeth, the gear ratio is 25 : 1. Part (B) of the figure shows a double thread worm. For each revolution of the worm in this case, the worm wheel turns two teeth. That makes the gear ratio 25 : 2 if the worm wheel has 25 teeth.

Worms can also have three, four, or more threads. The number of wheel teeth turned for each revolution of the worm is always the same as the number of threads on the worm. Since each thread of the worm moves only one tooth of the wheel, the gear ratio between worm and wheel is:

$$\frac{\text{The number of threads in the driving worm}}{\text{The number of teeth in the driven wheel}}$$

The worm and worm wheel setup has two chief advantages which determine its use. First, it has large gear ratio which can produce large speed reductions. This permits a small electric motor to drive a large load. The work done is the same, but the rate of doing the work is reduced. And second, it is not usually reversible; that is, the worm can drive the worm wheel, but the worm wheel cannot drive the worm. This is especially advantageous where two electric motors in a computer are driving two different quantities into one line through a differential. It prevents one quantity from backing up into the other. The backing up action would cause the output to be in error. There are a few unusual cases where the worm has several threads, and the slantwise pitch of worm wheel teeth is great enough so that the worm wheel can actually drive the worm, but these are exceptions.

Limit Stops

A limit stop is a mechanical safely device for arresting or limiting motion. They are usually used to prevent shafts from rotating further than they should. They are often used to keep handcranks or electric motors from driving past the limits of the mechanism to which they are connected. There are two general classes of stops. One limits the shaft motion to 360 degrees or less and the other limits the shaft to a certain number of revolutions.

The first type consists of three metal blocks, with inserted steel stop plates. Two of the blocks are fastened to the framework of the machinery close to the shaft that is to be limited. The third block is pinned to the shaft. For instance, if the blocks are set to limit the rotation to 180 degrees, then every time the shaft makes a half turn in either direction, the stop plate on the rotating block touches the stop plate on one of the fixed blocks. This prevents the shaft from rotating further. The fixed blocks can be set to limit any predetermined value. If one fixed limit stop is removed, the shaft will rotate almost 360 degrees.

The second type, as shown in figure 11–13, is the type most often encountered. This limit stop consists of a traveling nut on a threaded screw, a guide rod to prevent the traveling nut from rotating, and two adjusting nuts. The adjusting nuts are pinned to the shaft on either side of the traveling nut and turn with the shaft. The shaft is stopped from turning when the stop plate on one of the adjusting nuts hits against a stop plate on the traveling nut.

The distance between the adjusting nuts is accurately set before the stop is installed in the machine, to correspond

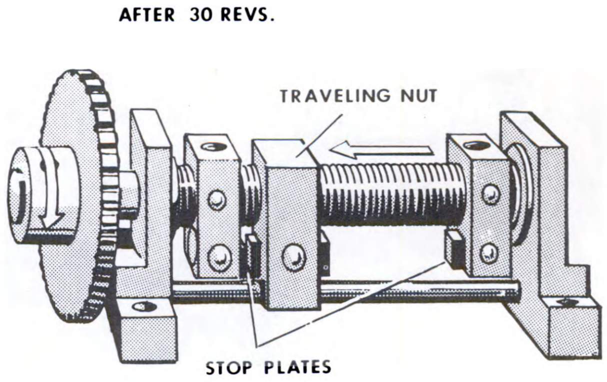


Figure 11–13.—Limit stops.

with the exact number of revolutions the shaft can make before it must be stopped. For example, a line is to be limited to 30 revolutions from its zero position. When the line is at zero the traveling nut will be against one of the adjusting nuts. After 30 revolutions of the line, the traveling nut will have traveled to the other adjusting nut, and will not be able to turn any further.

BASIC MECHANISM

Differentials

The mechanical differential is one of the most common basic mechanisms found in aviation equipment—usually in the computers. In one respect the differential is a computing device, because it can be used to ADD or SUBSTRACT two quantities. To put it more precisely, it adds the total revolutions of two shafts—or subtracts the total revolutions of one shaft from the total revolutions of another shaft—and delivers the answer by positioning a third shaft.

A differential will add or subtract any number of revolutions or very small fractions of single revolutions continuously and accurately. It produces a continuous series of answers as the inputs change.

There are two types of differentials—the bevel gear and the spur gear differentials. Because both types operate

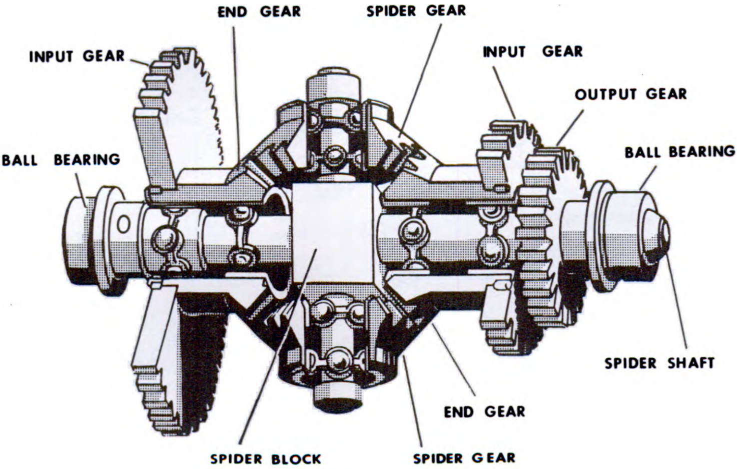


Figure 11–14.—Bevel gear differential.

fundamentally the same, we will discuss only one—the BEVEL GEAR DIFFERENTIAL.

A cutaway view of a bevel gear differential is shown in figure 11–14. The figure shows all the parts and how they are related to each other. Grouped around the center of the mechanism are four bevel gears, meshed together. These four gears and the spider shaft are the heart of the differential.

As shown in the figure, the two bevel gears on either side are called end gears and the two bevel gears above and below are called spider gears. The spider gears are meshed with the end gears. The cross shaft and spider gears together are called the spider and the long shaft is called the spider shaft. All four of the bevel gears are free to rotate on precision bearings. The three spur gears are used to connect the two end gears and the spider shaft to other mechanisms. They may be any convenient size, and any one of them can be either an input or an output.

In operation, the end gears which are fixed to the input gears drive the spider gears. The spider (or inner) gears "walk" around the end gear faces to turn the spider assembly and shaft. Rotation of the spider rotates the output gear which is pinned to the spider shaft.

First, consider either input gear held stationary while the other input gear is turning. The one that is turning will drive the spider gears. As the spider gears turn, they roll on the stationary end gear surface (attached to the stationary input gear). This results in a rotary motion of the spider shaft. Now consider both end gears rotating at equal speed but in opposite directions. The right end gear attempts to rotate the spider gears in one direction, while the left end gear tends to rotate them in the other direction. The result is zero rotation of the spider, and zero output. Mathematically, this is the same as subtracting two equal quantities.

Now let us consider both end gears rotating in the same direction and at the same speed. The resultant spider rotation will be PROPORTIONAL to twice the speed of either end gear. This is the same as adding two equal quantities. The spider output will not be the whole sum of the two inputs. Actually, the spider makes only HALF as many revolutions as the sum (or difference) of the revolutions of the end gears. This is because the spider gears are free to roll between the end gears.

Finally, consider holding the spider shaft stationary and turning one end gear. A study of figure 11–14 will reveal that the other end gear turns an EQUAL amount in the opposite direction.

It should be noted that it is not necessary to use the side gears or inputs and the gear on the spider shaft as an output. The spider shaft may be used as one of the inputs, and either of the sides used as the other. In this case, the second side becomes the output. This permits three different hookups for any given differential. In computers, any of the three hookups may be used, depending upon which proved most convenient mechanically.

The general equation of the rotation of the three gears is:

$$\theta_s = \frac{\theta_1 + \theta_2}{2}$$

where

θ_s=rotation of spider gear
θ_1=rotation of first end gear
θ_2=rotation of second end gear

Thus, if one end is rotated 6 times and the other end 4 times in the same direction, the spider rotates 5 times. (The factor 2 is a fundamental characteristic in differentials, and is always present, irrespective of gear ratios.) Suppose one end is rotated 6 times in a certain direction and the other end is rotated 4 times in the opposite direction, what is the rotation of the spider? *Answer:* One. If the spider is rotated 5 times and one end is rotated 7 times in the same direction, what is the output of the other end gear? *Answer:* Three rotations. (NOTE: $\theta_1=2\theta_s-\theta_2$.)

Cams

Mechanical computers often use cams to introduce various functions used in the solution of the fire control problem. These cams have many different shapes and sizes and do many different jobs as we shall see. There are two things that all cams do have in common; namely, a curved surface, and a follower.

The curved surface may be a groove, ridge, or contour that is positioned by the input. Each point along the curved surface represents a different output value. Every cam must have some device like a roller, ball, or pin that bears against the curved surface. As the input positions the cam, the follower registers the output value at the point that it bears against the curved surface.

There are two basic types of cams—the constant lead cam and the computing cams. In the latter each point on the output represents a function of the input, such as reciprocal, tangent, or square of the input.

The action of a cam can be seen by studying the CONSTANT LEAD cam in figure 11–15. The constant lead cam consists of a spiral groove cut in a circular plate. If the cam is rotated in one direction, the spiral will force the follower

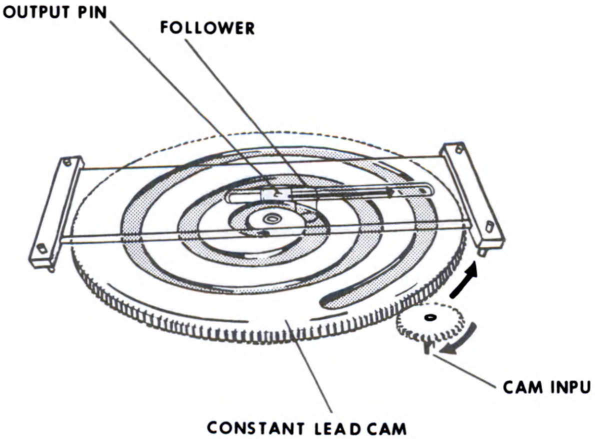


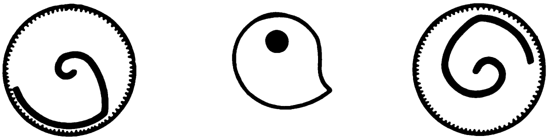
Figure 11–15.—Constant lead cam.

block outward from the center along a straight slot. If the plate is turned in the opposite direction, the spiral will force the follower block inward, toward the center.

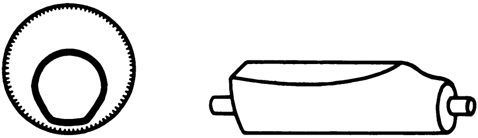
Notice the follower itself never travels to the center of the cam, and the output pin is offset on the follower block so that it can be positioned directly over the center of the cam. This is the ZERO position of the output pin. The offset of the output pin is necessary because, if the pin were allowed to travel to the center of the cam, it would remain there.

The constant lead cam is actually a special case for its output is simply a straight motion of the follower directly proportional to the rotary motion of the input. All other cams compute a function of the input.

Some of the other cams in use are shown in figure 11–16. Let us now briefly discuss each of these. One of the easiest ways to divide one number by another mechanically is to multiply the first number by the reciprocal of the second number. The reciprocal of a number is 1 divided by that number. A RECIPROCAL cam is made by laying out reciprocal values along the radii and connecting them by a curved groove. To get the reciprocal of a number, the cam is turned to the position corresponding to that number. The output



RECIPROCAL CAM FLAT CAM TANGENT CAM



SQUARE CAM BARREL CAM

Figure 11–16.—Cam types.

pin of the follower will then be a distance from the center corresponding to the reciprocal of the number.

Almost any table of values can be cut into a cam. Grooves can be cut to give most of the trigonometric functions. The TANGENT cam is an example. Except for the special tangent grooving, the tangent cam is like any other grooved cam. It can be mounted and used in exactly the same way. Its job is to give the tangent of an angle. The input is an angle; the output is the tangent of that angle. The SQUARE cam works like the trigonometric cams, but its groove is shaped to square the input quantity. Thus, if the input is 2, the output is 4; and if the input is 3, the output is 9, etc.

The FLAT cam can do a job similar to that of the grooved cams. But the follower rolls on its curved edge instead of sliding in a groove. The input rotates the same about its axis, and the output is positioned by the follower. Also, cams similar to the flat cam can operate mechanical devices to control electric relays or switches. Flat cams are found in many sizes and shapes, depending upon their applications.

The BARREL cam, sometimes called the three dimensional cam, has a shaped contour or body. It has two inputs; one rotates the cam about its axis, the other positions the follower laterally. The follower positions the output as it rides on the contour of the cam, and its position is a function of the two inputs. The barrel cam is seldom used in aviation equipment.

Multipliers

In the solution of the aviation fire control and bombing problems by means of a mechanical computer, it is often necessary to multiply two continually changing values to produce a continuous series of products. The device that accomplishes this is called a MULTIPLIER. These multipliers usually produce a solution through the use of similar triangles. (See *Mathematics*, NavPers 10069–A.) There are four types of multipliers in use—screw, rack, sector, and cam types.

SCREW TYPE.—The screw multiplier, shown in figure 11–17, has two inputs and one output. The inputs are shaft values which position the INPUT SLIDE and INPUT RACK. The output appears at the output rack which positions the output shaft. Thus the output shaft value is always proportional to the product of the two inputs.

One input gearing is connected to two long screws. These screws pass through the threaded sleeve-like ends of the slotted input slide. As the input gears to the screws are

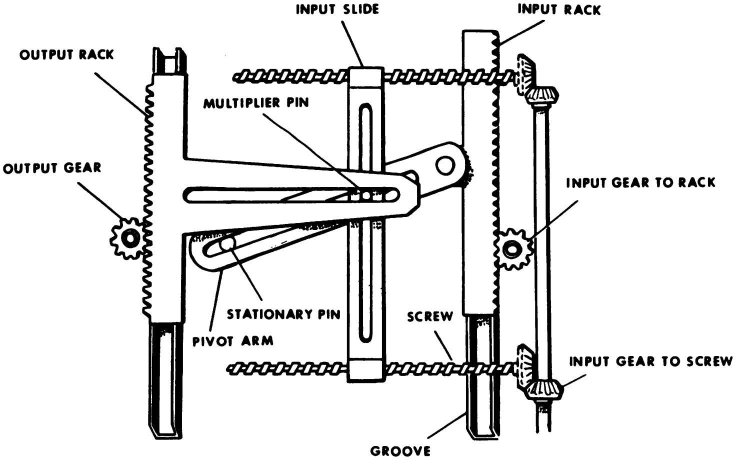


Figure 11–17.—Screw type multiplier.

rotated, the two screws turn to position the slide left or right. At the same time, the other input positions the input rack up or down, moving the slotted pivot arm around the stationary pin.

The multiplier pin is mounted in the slots of the input slide, pivot arms, and output rack, connecting all three where the slots cross. As the multiplier pin moves with the input slide and pivot arm, it positions the output rack and gear.

Now, consider the multiplier in the zero position shown in figure 11–18. If only the screws are rotated, the input slide moves to the right; but it will not affect the output rack. Similarly, if only the input rack is moved up or down from the zero position, the output rack will be unaffacted. This is a reasonable result for any number multiplied by zero is equal to zero.

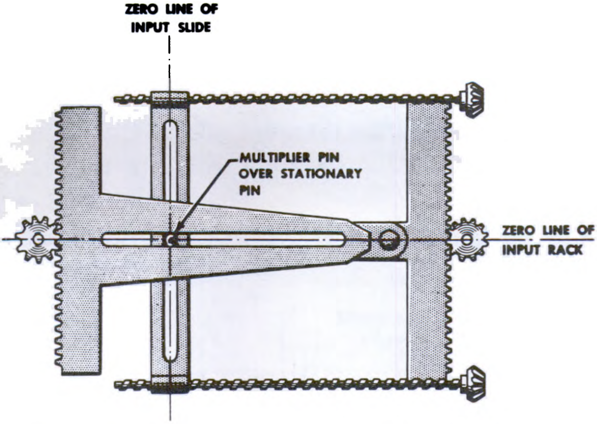


Figure 11–18.—Screw type multiplier—zero position.

From this we can conclude that both inputs must be removed from the zero position for an output. Such a condition is shown in figure 11–19. Notice the triangle superimposed on the device. The value a represents the amount of rack input. The value b represents the amount of slide input. K is a fixed distance, since the multiplier pin cannot move and the input rack travels in a machined guide rail.

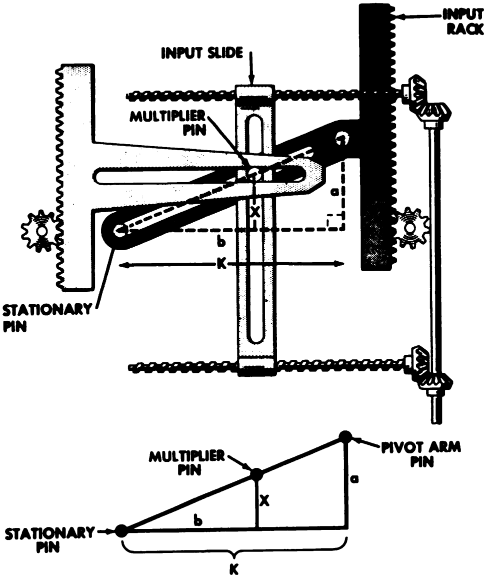


Figure 11–19.—Screw type multiplier—multiplying positive values.

Because the angles are equal, the triangles are similar. Thus the value of x can be determined if the other values are known.

$$(\text{Actually, } x=\frac{ba}{k}.)$$

This equation shows that the output (x) is always proportional to the product of the two inputs. The constant value (k) can be compensated for by the proper choice of input and output gearing for the multiplier. These multipliers can also determine the product of negative values.

Rack type.—The rack type multiplier in figure 11–20 performs the same task as the screw type multiplier. The differences are that (1) the screw input has been replaced with an input rack, and (2) the output rack is placed on the same side as the second input rack. As the screw type, the rack multiplier can handle both positive and negative values.

Notice in figure 11–20 that the rack type also employs

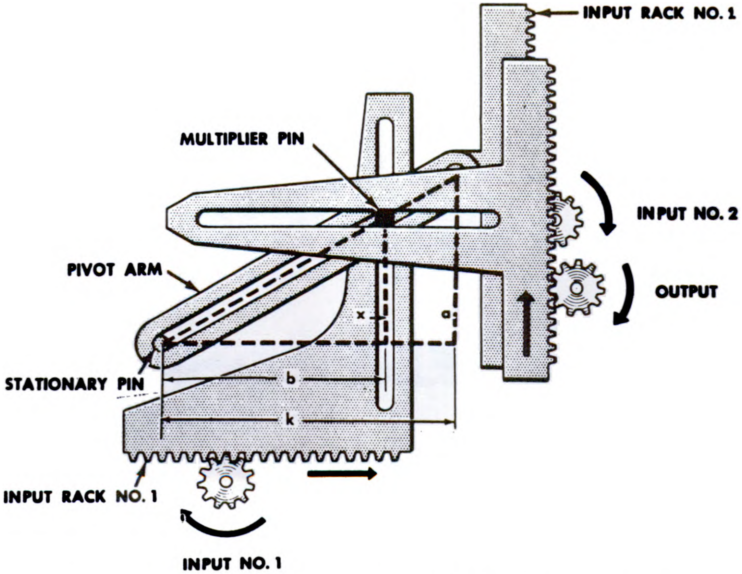


Figure 11–20.—Rack type multiplier—multiplying positive values.

similar triangles. The output is always proportional to the product of the two inputs. The output can be equal to the product by the use of the proper gear ratios. Zeroing of a rack type multiplier is similar to the adjustment of the screw type multiplier. As with most mechanical computing mechanisms, adjusting the rack type is largely the application of commonsense and mathematical principles.

SECTOR TYPE.—Although different in construction, the sector type also employs triangles for the multiplication of the two inputs. A sector type multiplier is shown in figure 11–21. One input positions the input sector arm and the other input turns a large screw that is mounted on the input sector arm. The bevel gear turns this lead screw through a universal joint. The use of the universal joint permits the input to drive the lead screw as the sector arm changes its angular position. Notice that the lead screw drives the multiplier pin up and down the sector arm. Thus the position of the input sector arm and the position of the multiplier on the lead screw represents the two values to be multiplied.

One end of the parallel arm in figure 11–21 is pivoted on the output sector arm by the connecting pin. The other end is mounted on the radius arm. The multiplier pin moves in the slot in the parallel arm. You can see why the slotted piece, which always moves parallel to a line through the three lower pivot pins, is called a parallel arm. Since the slot is at right angles to the parallel arm, it is always perpendicular to the base line.

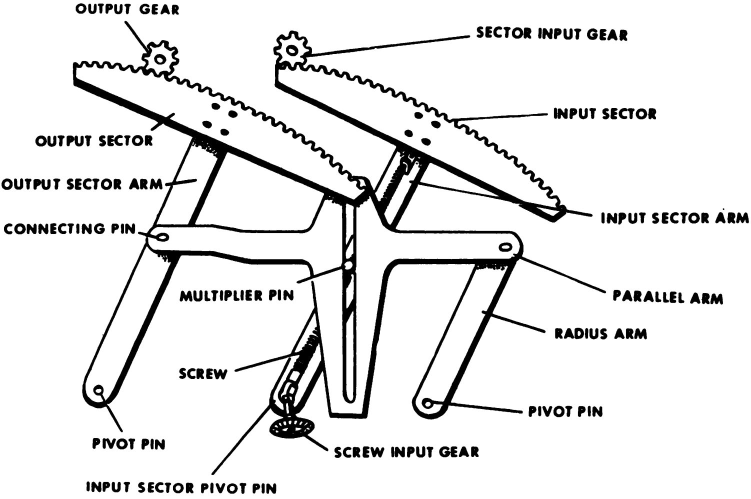


Figure 11–21.—Sector type multiplier.

A study of figure 11–21 will reveal how the output section arm will move in response to either the movement of the input sector or the movement of the multiplier pin on the sector arm. Of course, if either of the input quantities is zero, movement of the other input will not produce any output.

One zero input occurs when the lead screw on the input sector arm is parallel to the slot in the parallel arm. The other zero input occurs when the multiplier pin is directly above the pivot point of the input sector arm. Movement of the multiplier pin when the screw is vertical will not affect the parallel arm and therefore the output sector. Similarly, movement of the input sector when the multiplier pin is at the pivot point will not affect the parallel arm and output sector.

Consider now how the combination of the two inputs has positioned the sector arm and multiplier pin in figure 11–22. Two right triangles have been formed. Side *c* is the same length in both triangles. *K* is the hypotenuse in the left triangle, while *a* is the hypotenuse in the right triangle.

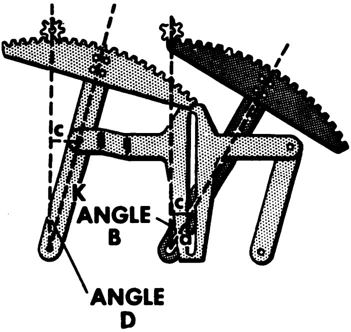


Figure 11–22.—Multiplying with the sector type multiplier.

Based on the fact that *c* is the same length in both triangles, it can be shown that angle *D* in radians is equal to *a* times angle *B* in radians divided by *k*. Since these angles are expressed radians, the radian value of angles *B* and *D*, which measures the motion of the sectors, can now be substituted for the angles in each case. Thus, output *D* is the product of the two inputs divided by the constant *k*. The output is PROPORTIONAL to the product of the two inputs.

A study of figure 11–21 shows the negative quantities can be introduced on the input sector. However, the multiplier pin position runs only from zero to positive values as it cannot run below the pivot point of the input sector arm. While the sector type multiplier can handle both positive and negative inputs on the input sector arm, the input to the lead screw must always be a positive quantity.

CAM TYPE.—The cam computing multiplier is a dual operation device. It computes a function of one value on a cam and multiplies that function by a second value. It is a combination of a cam and a rack type multiplier.

A single cam computing multiplier is shown in figure 11–23. Notice it is like the rack type multiplier except that one of the inputs is positioned by a cam instead of a rack. The cam follower pin is mounted directly on the multiplier input slide. This cam may be cut to compute any desired function of the cam input.

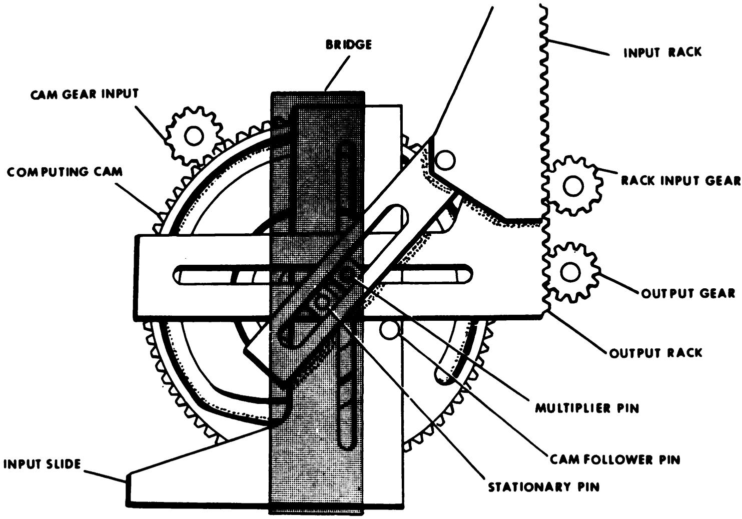


Figure 11–23.—Single cam computing multiplier

One input drives the input rack through the rack input gear. The other input drives the cam directly. The cam positions the input slide according to the function for which the cam was cut. Thus the cam output becomes the slide input. The position of the output rack represents a value which is proportional to the product of the cam output and the rack input, just as in the rack type multiplier.

A two-cam computing multiplier computes the function of both inputs and multiplies these functions together. The output is proportional to the product of the functions of the two inputs.

MAGNETIC CLUTCH

The magnetic clutch is a device that uses the same principles as the solenoid. It usually is used to connect or disconnect a line of gearing. By use of a solenoid and electrical circuit, the magnetic clutch is easily energized. The clutch itself may be the friction type; that is, made of cork, bakelite or other friction material. Other clutches use a mechanical interlock such as the sliding jaw shown in figure 11–24.

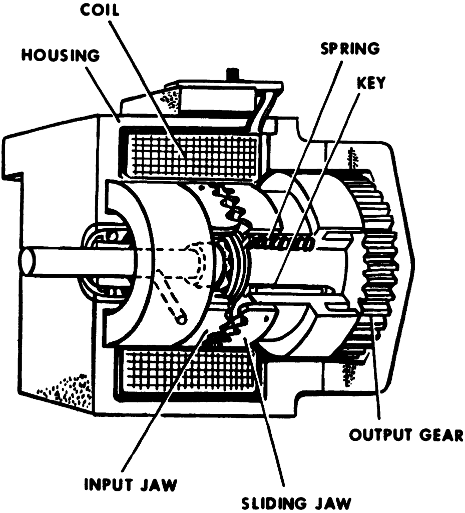


Figure 11–24.—Magnetic clutch.

This magnetic clutch consists of two cylindrical jaws set inside a solenoid coil. As shown in figure 11–24, the input shaft rotates one jaw; and the other jaw is mounted on the hub of the output gear. The output or sliding jaw is free to slide back and forth, while the input jaw is pinned to the shaft. In the deenergized position, three springs hold the sliding jaw out of engagement with the input jaw.

When the current is applied to the solenoid, a magnetic field is developed. Both jaws become magnetized and the opposite poles of the magnets attract each other. The sliding jaw is pulled into mesh with the input jaw and the two jaws turn together. In this position, the output shaft will be driven by the input shaft. When the current stops in the solenoid, the magnetic field collapses and the springs disengage the jaw.

Because magnetic clutches are constructed to fit the requirements of the equipment, there are a great many types and sizes. However, their operation is fundamentally the same.

PRINCIPLES OF THE GYROSCOPE

As you know, one of the factors in the solution of the fire control problem is the determination of angular rate of change. In order to use this information in the solution of the problem, some means must be obtained to measure this rate of change of angle with considerable accuracy. As mentioned previously, some fire control equipments use methods based upon the gyroscopic principles. Besides being used as a rate gyro, the gyroscope is also utilized as a means of obtaining a stable vertical or horizontal reference. Therefore, let us now investigate the basic operation and principles of the gyroscope.

A gyroscope is a spinning wheel or rotor which is universally mounted, that is, mounted so it can assume any position in space. The model gyroscope shown in figure 11–25 portrays a rotor that is free to spin about axis X–X on bearings in the inner ring or gimbal. The inner gimbal is free to turn about axis Y–Y on pivots in the outer gimbal. The outer gimbal is free to turn about axis Z–Z on pivots in the support. However, the illustrative model is a gyroscope in name only; it does not exhibit gyroscopic properties until the rotor is spinning. To understand the functioning of any gyroscope, it is necessary to understand two fundamental properties of an operating gyro.

When the rotor of a gyroscope is spinning, its axis of rotation tends to remain in a fixed direction of its axis. Since the axis is at right angles to the plane of rotation of the rotor, any change in orientation of the plane of the rotor is resisted. This property of any operating gyro is called

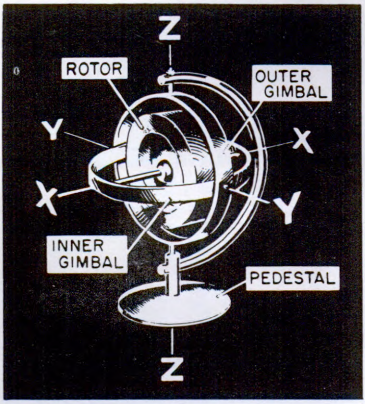


Figure 11–25.—Elements of a gyroscope.

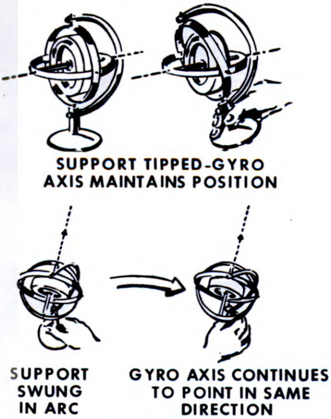

SUPPORT TIPPED-GYRO AXIS MAINTAINS POSITION
SUPPORT SWUNG IN ARC
GYRO AXIS CONTINUES TO POINT IN SAME DIRECTION

Figure 11–26.—Gyroscopic inertia.

gyroscopic inertia, or, more simply "rigidity." In figure 11–26 the axis of rotation of the spinning rotor is horizontal. If the support is tilted, the inner gimbal, in which the rotor spins, remains horizontal. If the support is swung in an arc, the spin axis continues to point in the same direction.

The rigidity of a gyroscope may be increased by making the wheel heavier, by causing it to spin faster, or by constructing it so that a larger portion of its weight is concentrated near the circumference. As it is impossible to make bearings entirely free of friction, in most gyros friction is kept to a minimum, and the rotors are designed to have a great deal of rigidity. Whatever friction remains is so small in comparison to the great rigidity of the heavy, rapidly-spinning rotor that its effect upon the operation of the gyro is extremely slight.

An operating gyro will resist a force which attempts to change the direction of its spin axis, but it will move in response to such a force or pressure. The movement is not a direct one in response to the force; it is a resultant movement. The gyro axis will be displaced, not in the direction of the applied force, but in a direction at right angles to the applied force, and in such a way as to tend to cause the direction of the rotation of the rotor to assume the direc-

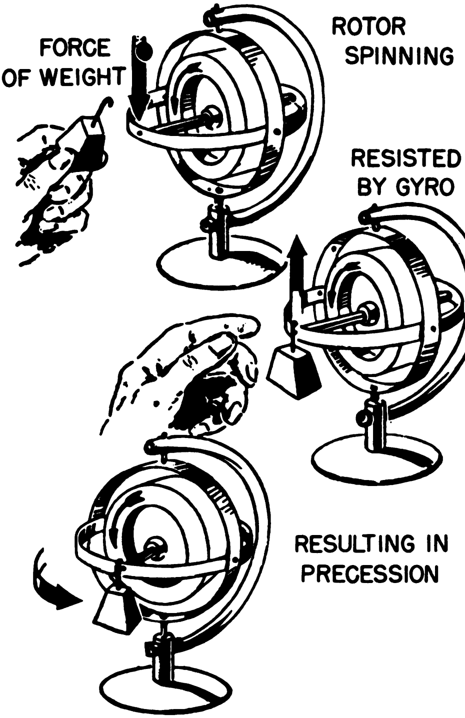


Figure 11–27.—Gyroscopic precession.

tion of the torque resulting from the applied force. This property of an operating gyro is called gyroscopic precession, as shown in figure 11–27.

For a given force, the rate of precession is governed by the weight, shape, and speed of the wheel. These factors are the same as those that determine the rigidity of a gyroscope. Therefore, it is reasonable to assume that there is relationship between the rigidity of a gyroscope and the rate at which a given force will cause it to precess. Such a relationship does exist. The greater the rigidity of the gyroscope, the more difficult it is to cause precession, the slower the precession for a given force will be.

The direction of precession in response to an applied force depends upon the direction in which the rotor is spinning.

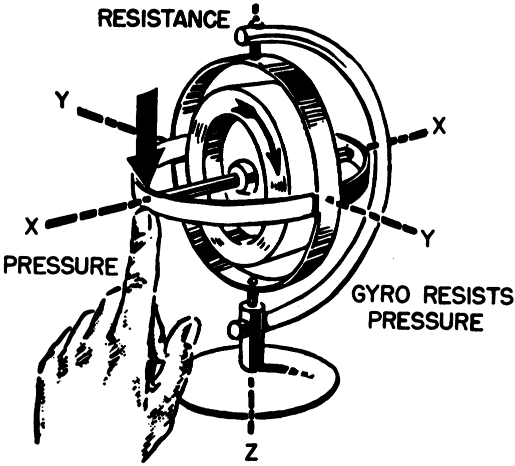


Figure 11–28.—Force applied to a gyro.

The precession is in such a direction that the wheel turns, through the smaller distance, toward a position in which the force would be acting about the spinning axis, in the direction of the spin.

The forces acting on a gyroscope may be represented graphically as acting on the rotor itself, spinning freely in space, with a plane containing each of the axes of freedom.

For example, when a force is applied upward on the inner gimbal, as shown in figure 11–28, the force may be visualized as applied in an arc about axis *Y–Y* until it contacts the rim of the rotor at *F*, as in figure 11–29. The effect produced by the force is equivalent to that produced by a force applied upward to the inner gimbal. The force at *F* is opposed by the resistance of gyroscopic inertia, preventing the rotor from being displaced about axis *Y–Y*. With the rotor spinning clockwise, the precession will take place 90 degrees ahead in the direction of rotation at *P*, as in figure 11–29. The rotor turns about axis *Z–Z* in the direction of the arrow at *P*, as in figure 11–30.

It should be clearly understood that most forces, when applied to the gyro mounting or support, do not cause precession. Recall when the support was tipped and swung in

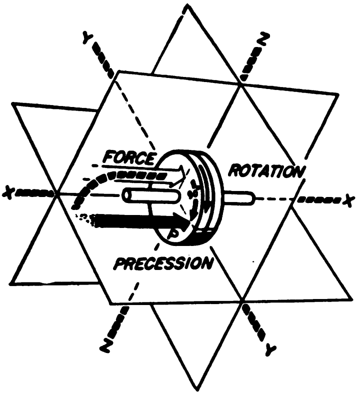


Figure 11–29.—Direction of precession.

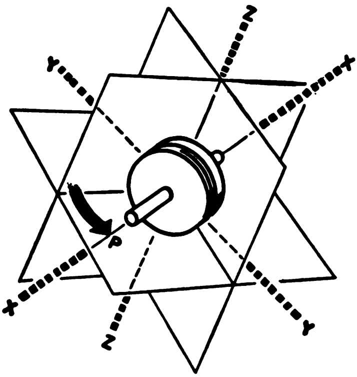


Figure 11–30.—Precessional movement.

an arc, the gyro axis maintained the same direction. (See fig. 11–26.) As the support is moved around in any direction, the motion is taken up in the *Y–Y* and *Z–Z* axes. Thus you can see that if the base of the gyro were attached to the frame of an aircraft, the gyro would have no tendency to precess as the aircraft rolled and pitched.

Similarly, a force applied about the spinning axis *X–X* of a gyroscope does not attempt to change the plane in which the rotor is spinning, therefore cannot cause precession. The only effect such a torque can have on the rotor is to increase or decrease its speed. In a gyro, the friction of the rotor bearings and the resistance of the air in which the rotor spins exert this kind of force. But sufficient power is supplied to the rotor to overcome this force and keep the rotor spinning at a constant rate.

These two fundamental properties are utilized in gyroscopic instruments. Gyroscopic inertia establishes a reference in space, unaffected by movement of the supporting body. Precession is utilized to control the effects of drift, whether it is apparent drift or mechanical drift, and maintains the reference in the required position.

A free gyro (one not provided with an erection system) maintains its axis fixed in relation to space, and not in rela-

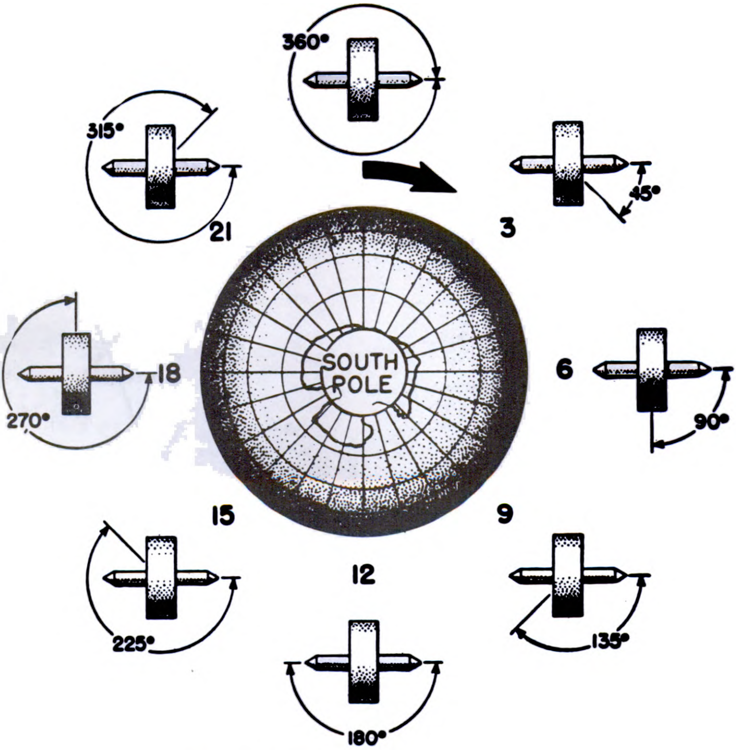


Figure 11–31.—Action of a free gyro.

tion to the surface of the earth. For example, imagine such a gyro at the Equator, its starting position being with the spin axis horizontal and pointed in an east-west direction. (See fig. 11–31.) The earth turns in the direction of the arrow, or clockwise, with an angular velocity of one revolution every 24 hours. To an observer out in space, the spin axis would appear to maintain its direction pointing east.

However, to an observer on the earth, stationed where the gyro is, the spin axis appears gradually to tilt or drift. At the end of 3 hours the spin axis has tilted 45 degrees; at the end of 6 hours, the spin axis has tilted 90 degrees and is in a vertical position. At the end of 12 hours the spin axis is again horizontal but pointing west; at the end of 24

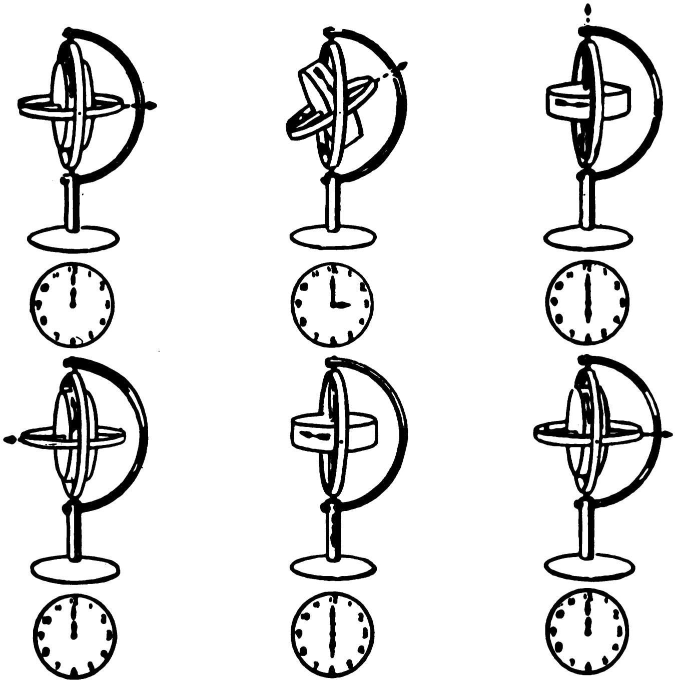


Figure 11–32.—Apparent drift.

hours it is back where it started. (See fig. 11–32.) This action of a free gyro is known as apparent drift. To overcome apparent drift as well as mechanical drift caused by bearing friction or slight unbalance, a gyroscopic instrument must be provided with an erecting device which maintains the spin axis in the required position. This erecting device applies a force to the gyro whenever drift occurs. Precession returns the spin axis to its normal position, maintaining an accurate reference.

By using a gyroscope with an erecting mechanism within an airplane, stabilized reference is provided. As the airplane rolls or pitches, the spin axis remains upright. When an appropriate indicating device is attached to the gyro, deviations from the normal attitude of the airplane will be shown. By referring to the indications, the pilot may control the airplane. These changes in aircraft axis are also converted into electrical signals and used in solution of the fire control problem by special computers in the armament control systems.

HOOKE'S JOINT

You will recall in our discussion on lead-computing sights it was pointed out that the sight unit was the heart of the system. Also recall that the sight computes the lead angle using the principles of a rate gyroscope.

In both the Mk 8 and Mk 11 sight units the gyro unit contains a motor driven gyroscope which is merely a mirror assembly spinning at high speed. The gyro tends to remain pointing in a fixed direction. When the aircraft turns, the sight unit also turns around the gyro.

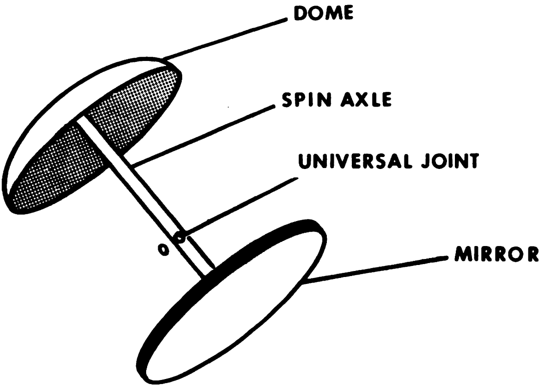


Figure 11–33.—Gyro dome, axle, and mirror.

The type of gyro dome, axle, and mirror used in these sight units is shown in figure 11–33. Apparently, this type of gyro is different than the ones we have just discussed. Nevertheless, the basic principles of operation is the same. You will also recall that the dome in these sight units rotates in a magnetic field produced by electromagnetics. By controlling the currents in the windings of the electromagnets, information can be inserted to control the dome, the mirror, and thus the sight line.

Now, in order that the gyro will be free to tilt in any direction, a universal joint arrangement is used. The Hooke's joint is such a universal joint used to mount the gyro rotor in these sight units. Through a pulley arrangement, the spin axle (therefore the dome and mirror) is kept rotating by a constant speed motor. This arrangement is shown in figure 11–34.

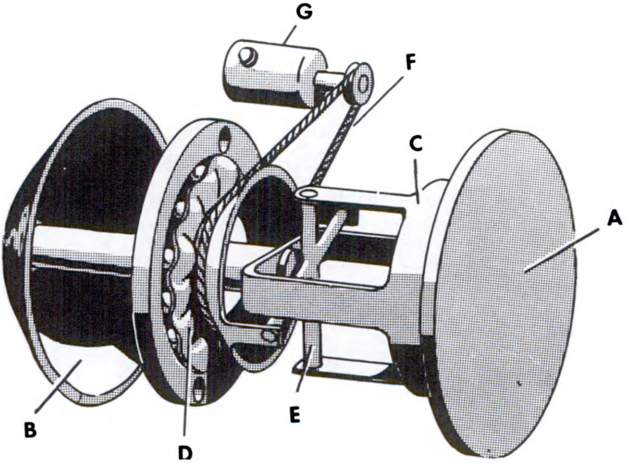


Figure 11–34.—Gyro assembly using Hooke's joint.

The lettered parts in figure 11–34 are: (A) mirror, (B) dome and stem assembly, (C) coupling, (D) pulley and bearing assembly, (E) pivot and hub assembly, (F) spring pulley belt, and (G) motor.

The pulley and bearing assembly supports the entire gyro. The outer bearing race and flange are mounted to the frame of the aircraft. The inner race and pulley are connected to the gyro. Thus the entire gyro will rotate on the ball bearings and is driven by the motor and pulley spring.

The pivot and hub assembly is supported on pivot bearings by the pulley and bearing assembly. The coupling holds the mirror on one side of the hub assembly and is connected to the stem and dome assembly on the other side of the hub through the hub axes.

The pivot and hub design of the Hooke's universal joint makes it possible for the pulley and bearing to rotate in a fixed plane, yet allows the gyro and mirror to spin around a variable axis. In order to prolong the service life of the gyro, the pivots of the Hooke's joint are equipped with lubricating washers. A shield is provided for the bearing in the pulley and bearing assembly to assist in protecting the bearing against the entrance of foreign particles.

CLEANING AND LUBRICATION

Many mechanical computing devices used in aviation fire control equipment are highly machined and are close tolerance mechanisms. The accuracy of these fire control systems is often dependent upon the operation of these mechanical devices. Any dirt, dust, or other foreign particles may cause them to operate inaccurately. Moisture may cause corrosion which may also cause inaccuracy. Excessive wear will cause inaccuracies and shorten the life of the equipment. Thus, it can easily be seen the cleaning, lubrication, and moistureproofing of close tolerance parts is necessary to have accurate effective equipment.

Many units are sealed from dust and foreign particles by dust covers or panels. These covers are attached to the unit by retaining screws, and rubber gaskets are used to keep them sealed from the outside dirt and dust-laden air.

These units usually use an air drier, or desiccator unit, to moistureproof the mechanisms within the unit. The unit is sealed by dust covers and is airtight except for the connection to the air drier. The air drier consists of a unit that contains silica gel crystals. The silica gel crystals absorb moisture from the air within the unit. Due to the changes in altitude the air drier must also allow the unit to "breathe." As the outside air pressure increases or decreases, the inside air pressure must also increase or decrease with it. The air drier is positioned so that the air coming into the unit must pass through the silica gel crystals.

When the unit is removed from the aircraft and taken to a maintenance shop, adequate provisions must be made to keep the mechanisms clean and dry. Before the unit is disassembled, all dirt, dust, grease, and other foreign matter must be removed from its outside surface. The working surfaces of the unit, the components or subcomponents to be worked on, must be as clean and dry as circumstances permit. Whenever the unit is disassembled, all components and subcomponents must be kept under lint-free dust covers (cloths) to protect them from foreign matter, except during the time they are actually under test, repairs, or lubrication.

Cleaning

Even after the previous precautions are taken, there will be some dirt and other foreign matter that may penetrate into the equipment. Also, it may be necessary to remove excessive or old oil and grease. The solvent that should be used for mechanical parts is Federal Specification PS–661. If some other solvent is to be used, it will be specified by the *Handbook of Service Instructions.* The correct solvent MUST be used since some solvents leave a residue or cause corrosion. Therefore, ALWAYS check the maintenance manual.

Spraying or splashing of the solvent must be avoided during cleaning. If the solvent were to fall upon a bearing surface, it would cut or render the lubricant less effective, causing excessive wear. After the solvent has been used, the parts must always be wiped dry with a clean lint-free cloth.

Friction clutches, such as cork, should be cleaned to insure that the surface is free from dirt or lubricants. This can be done by using a piece of clean paper dipped in alcohol. The paper is inserted between the cork disk and the clutch surface. Now by rotating either one of the two surfaces, the cork will be cleaned. Repeat this operation, using a fresh piece of paper each time, until it no longer reveals any dirt. Do not allow the cork to be contaminated by oil, for this will cause the clutch to slip.

Lubrication points must be cleaned prior to lubrication. Abrasive material may be forced into the bearing surfaces if all lubrication points are not cleaned before applying the lubricant. After these lubrication points have been cleaned, they must be wiped dry of the cleaning solvent with a clean lint-free cloth.

Lubrication

Lubricants are used to reduce friction and to assure wear-free, effective operation of moving parts, as well as of the system. Occasionally, lubricants are used for the purpose of preventing rust, oxidation, and corrosion. The *Handbook of Service Instructions* includes the lubrication instructions for the particular equipment. But no lubrication procedure will be effective unless it is performed regularly. Different components must be lubricated at different intervals; the recommended frequency of lubrication for each component must be followed. The use of a checkoff list is advised both as a guide and as a record of maintenance performed.

Excessive lubrication can cause almost as much harm as lack of lubrication by collecting foreign matter on the parts where the excess lubricant has accumulated. In the case of electrical components, the lubricant may work into the windings causing failure of the part. Do not attempt to lengthen the lubrication interval by increasing the amount of lubricant applied. Never lubricate an electrical contact surface.

The lubricant should be applied uniformly and in small quantities by means of a long-handled sable's- or camel's-hair brush, a spatula, or a hypodermic needle. When using the needle, first force one drop of oil to the tip of the needle; then touch the drop to the part to be oiled. If a hypodermic needle is not available, dip a clean piece of small diameter copper wire (approximately 24-gage) into the oil and allow all but one small drop to drain off. Then apply the drop to the part to be oiled.

Inasmuch as aviation fire control equipments contain many different types of moving parts, a particular lubricant and the amount to be used is specified for each lubricating point. Publications applicable to the particular equipment under consideration will tell you when to lubricate, what type of lubricant to use, how much to use, and where to put it.

EQUIPMENT REMOVAL AND REINSTALLATION CONSIDERATIONS

Planning is the most important step in the removal of units from an aircraft or assemblies from a unit. Planning must cover such items as obtaining correct tools, removing hazards to personnel and equipment, shop space, and reinstallation considerations prior to the actual removal. If these things are not considered, there may be time lost, personnel injured, or the equipment damaged.

Major Units

To remove a major unit from an aircraft for maintenance, periodic check, or lubrication, the first step is planning. The route the unit must take from its mounts in the aircraft to the shop bench space must be cleared. This will include removing cables, possibly parts of the aircraft equipment, and obstacles, such as aircraft emergency equipment, etc. It also includes clearing and cleaning workbenches for the unit.

Since electrical connectors are keyed and are of different types, they merely need to be disconnected and placed clear of the removal path of the unit. The alinement of the mechanical connections must be noted for reinstallation considerations. If these mechanical connections have zero positions, they should be disconnected at zero and marked or tagged. Mating gears should be marked at their mating points.

The proper and necessary tools must be obtained. Wrenches, screwdrivers, pliers, and if the equipment is extremely heavy, a hoist, may be required. If help is needed, the personnel must be obtained. The entire removal procedure must be thoroughly explained to them, accentuating to each man his specific job. The person in charge of the removal will issue all instructions, timed so that the result will be a smooth effective operation. The work should be done with caution to eliminate the possibility of injury and damage to the equipment. Observe all the safety precautions.

When the unit is in the shop, certain precautions should be followed prior to disassembly. The outside of the unit should be cleaned, as discussed in the previous section. When the dust covers are removed, any rubber gaskets in use should be inspected. If found damaged, new ones must be obtained. It should be emphasized that the correct procedure for removing or reinstalling any particular major unit will be found in the maintenance manuals for the equipment.

Assemblies and Subassemblies

In the removal of mechanical assemblies and subassemblies, planning is also one of the requirements. The connections between the assemblies may be by gears, shafts, linkages, or possibly electrical cables. Whatever the type of connection, considerations must be made for their alinement upon reinstallation.

Some equipments using mechanical components are alined by the use of setting pins. The equipment is so designed that with all the pins in position, the assembly is in the proper alined condition for reinstallation. These pins are sometimes called zero setting pins. These setting pins, however, are not used in all connections. Therefore, upon removal of assemblies, it may be necessary to note the alinement of the gears, shafts, etc. prior to the actual removal.

Gears that rotate less than one revolution, a mark at the point where the gears mesh will indicate reinstallation alinement. Both gears must be marked, and upon reinstallation these marks are matched.

Gears that rotate through several revolutions between limit stops are also marked. However, this should be made while the gears are against one of the limit stops. A tag should be placed on the gear shaft containing the information which limit stop was used. If the gears cannot be disconnected at a limit stop, the number of revolutions from the stop should be counted. Again a tag is necessary and must contain this alinement information.

Shaft alinement is somewhat easier since most equipments utilize quick-disconnect couplings. For a shaft that does not rotate more than one revolution, a mark on both ends of the coupling will indicate the alinement position. This will eliminate the possibility of the connection being made 180 degrees from the correct alinement position.

A shaft that rotates through several revolutions between limit stops should be marked at one of the stops. If the disconnection cannot be made at a limit stop, the number of revolutions from the limit stop is counted, and the shaft is tagged with the alinement information. It is important NOT to rely on your memory for alinement information. The alinement information should be recorded and attached to the connector used.

Linkages normally will not require alinement. However, if they do require alinement, the maintenance manual will contain the necessary information.

Reinstallation

Reinstallation is usually just the reverse of the removal procedure. Special consideration should be made for gear mesh, coupling, and linkage connections.

The mesh of gears is extremely important. Improper mesh can cause excessive wear, binding, and shorten the life of the equipment. If the gear faces do not mesh squarely, the gear teeth will wear excessively and may bind. If the mesh is square but too tight, there will be no lost motion. (Lost motion is the distance the driver gear turns before the driven gear begins to turn.) No lost motion results in excessive wear to the gears.

Before quick-disconnect couplings are connected, their shafts should be checked for alinement. If the shafts are at an angle to each other, they may bind. When linkages are connected, the connecting pin or bolt must be checked to insure that with the motion of the linkage it will not catch or cause the linkage to bind.

Electrical connectors must be connected carefully to prevent the bending or breaking of the connecting pins. Do not attempt to connect a plug to the wrong receptacle.

All connections must be made securely. All connections, both mechanical and electrical, should be inspected to insure that they are properly alined. After a unit has been reassembled and the dust covers securely replaced, the silica gel crystals should be checked. If necessary, they should be heated until a bright blue color returns. Care must be taken in handling of these crystals as their moisture absorbing ability will be decreased if they are crushed. After checking, the crystals should be replaced in the air drier.

QUIZ

1. A pinning support is essentially a
    a. clamp to support the pin in a shaft to prevent it from dropping out
    b. rack self-supported used for storing spare parts
    c. metal bar with a V-shaped slot with a notch at the bottom used to support a shaft or part being pinned
    d. collar that slips over the pin in a shaft to keep the pin tight
2. The most common method used to secure a tapered pin to a shaft is done by
    a. heating the shaft and inserting the pin (sweating)
    b. threading the pin and the shaft hole (threading)
    c. staking a portion of metal over the large end of the pin (staking)
    d. bending the small end of the pin over (locking)
3. A backup tool is used to
    a. support shafts and collars being pinned
    b. turn a shaft that cannot be turned by hand
    c. prevent a shaft from rotating
    d. remove a broken (headless) screw
4. A bearing punch is used to
    a. remove defective bearings
    b. remove and insert bearings
    c. insert balls in the bearing race
    d. remove the bearing race from bearing
5. A coupling device for coupling two shafts at an angle to each other is a
    a. sleeve coupling
    b. universal joint
    c. sleeve and clamp
    d. quick-disconnect
6. When it is necessary to remove an assembly or subassembly for lubrication or alinement, the type of shaft coupling that is designed for this is the
    a. pinned sleeve coupling
    b. universal joint coupling
    c. sleeve-and-clamp coupling
    d. quick-disconnect coupling

7. If a driven gear and its driver gear are of the same size the gear ratio will be
   a. 1:1
   b. 2:1
   c. 4:1
   d. 5:1
8. When two gears of different sizes are meshed, the smaller gear is called a/an
   a. idler gear
   b. pinion gear
   c. spur gear
   d. spiral gear
9. It is possible to transmit motion of shafts at some angle other than straight by use of
   a. spur gears
   b. internal gears
   c. bevel gears
   d. sector gears
10. The worm and worm wheel gear setup has a gear ratio that is found by
   a. multiplying the number of threads on the worm by the number of teeth in the wheel
   b. dividing the number of teeth on the wheel by the number of threads on the worm
   c. dividing the number of threads in the worm by the number of teeth on the worm wheel
   d. adding the number of threads on the worm with the number of teeth on the worm wheel
11. Limit stops are used
   a. for limiting or arresting mechanical motion
   b. for controlling amount of power continuously applied to a gear
   c. to set the number of times a machine can be stopped and started over a given period of time
   d. to limit the amount of current flow in an electric motor
12. That property of a spinning gyro which resists any change in the orientation of the plane of the rotor is called
   a. rigidity
   b. friction
   c. precession
   d. rotation

13. In the basic differentials of fire control computers there is always
   a. one input and two outputs
   b. one output and two inputs
   c. one input and one output only
   d. a negative input and a positive output

14. If +3,600 r.p.m. was put in on differential side gear and —3,330 r.p.m. put in on the other side gear, what r.p.m. would come off the spider?
   a. 33 r.p.m.
   b. 150 r.p.m.
   c. 300 r.p.m.
   d. 1,800 r.p.m.

15. If +3,600 r.p.m. was put in on a differential side gear and the other side was held, what r.p.m. would come off the spider?
   a. +3,600 r.p.m.
   b. +1,800 r.p.m.
   c. +150 r.p.m.
   d. +36 r.p.m.

16. Division is normally accomplished in mechanical computers by using a multiplier
   a. in reverse
   b. and a differential
   c. and a reciprocal cam
   d. and a squaring cam

17. The screw type multiplier accomplishes multiplication by the use of
   a. similar triangles
   b. gear ratio of the screw
   c. cams and gear ratios
   d. cams and triangles

18. The output of the rack type multiplier will equal the product of the two inputs
   a. at all times
   b. only with the proper output gear ratio
   c. only with the proper input gear ratio
   d. with proper input or output gear ratio

19. If a gyro rotor speed is increased,
   a. it will be easier to precess
   b. its rigidity will increase
   c. there will be no difference in ease of precession
   d. there is no relation between a gyro's rigidity and rotor speed

20. A free gyro is referenced to
    - a. a point in space
    - b. the center of the earth
    - c. magnetic North Pole
    - d. true North Pole

21. To maintain a gyroscope's spin axis pointed toward a fixed point on the earth's surface, the gyroscope must
    - a. use precession
    - b. be a free gyro
    - c. be a rate gyro
    - d. have great rigidity

22. The direction of precession of a gyro in response to an applied signal depends on
    - a. the direction in which the rotor is spinning
    - b. the amount of force applied
    - c. the rigidity of the gyro
    - d. its apparent drift

23. The solvent to be used, unless otherwise specified, when cleaning mechanical parts is
    - a. alcohol
    - b. carbon tetrachloride
    - c. kerosene
    - d. Federal Specification PS–661

24. The first step in the removal of a major unit from an aircraft is
    - a. planning the entire procedure
    - b. electrical cable disconnection
    - c. mechanical linkage disconnection
    - d. shop space clearance

25. Silica gel crystals, when dry and ready for use, are of what color?
    - a. Dark red
    - b. Pale pink
    - c. Light green
    - d. Bright blue

CHAPTER 12

BORESIGHTING

Usually when an aircraft is to be boresighted, a crew of Aviation Ordnancemen and Aviation Fire Control Technicians is formed. When the aircraft is at the boresighting area, this crew alines the aircraft, boresights the guns, gunsight, gun camera, and, if required, the radar antenna. The AQ's responsibility during boresighting is to boresight the sight and, if required, mechanically boresight the radar antenna. As part of the crew, he may also assist in the alinement of the aircraft, screen, and other general boresighting jobs. In some situations, he may be required to assist in the boresighting of the guns, gun camera, and the rocket launchers. Therefore, he should understand the entire boresighting procedure. Further, he should know and follow all safety precautions.

It should be noted that the boresighting of the radar may be done electrically or mechanically depending upon the equipment. As reflected in the "quals," the AQ1 is responsible for the performance of electrical boresighting of radars. The *Handbook of Service Instructions* contains the specific information for each particular piece of equipment.

THEORY OF BORESIGHTING

Purpose

In previous chapters the need for accuracy in adjustment and maintenance of aviation fire control equipment has been pointed out. However, in order to obtain accuracy of fire in gun (and rocket) installations it is necessary that a definite relationship be established between the line of sight and the line of fire. When the sight is located near the guns, as in some turret installations, the line of sight and line of fire are practically parallel. In gun installations where the gun is located at a distance from the sight, as in all forward firing (fixed) guns, the line of fire usually intersects the line of sight. In either case, it is necessary to establish the correct relationship between the line of sight and the line of fire. BORESIGHTING is the process by which the axis of a gun bore (or rocket launcher) and the line of sight of a sunsight are made parallel or are made to converge on a point.

Definition of Terms

As in most procedures, to understand them thoroughly, you must know the exact meaning of the terminology used. Therefore, let us first consider the terms associated with boresighting.

FLIGHT LINE.—The flight line is the line in space along which the airplane is moving.

ARMAMENT DATUM LINE.—A longitudinal reference line fixed relative to the airplane by boresight posts provided for that purpose. This line is used as a reference in boresighting. Thus, it is sometimes called the boresight datum line. (See fig. 12–1.)

ANGLE OF ATTACK OF ARMAMENT DATUM LINE.—This is the angle between the armament datum line and the flight line. This angle may be positive or negative, depending on the attitude of the airplane relative to the flight line. It is defined as positive when the armament datum line is above the flight line; that is, when the airplane flies nose-up relative to the flight line. The angle of attack varies with airspeed, weight, and dive angle. It is also affected by accelerations in flight.

ZERO SIGHT LINE (GUNSIGHT LINE).—This is the sight line through the fixed pipper of the computing sight. It is parallel to the armament datum line.

LINE OF SIGHT.—The line from the eye to the impact point. For a zero sight angle, this line will be through the pipper of the sight. Otherwise, it will be through a point in the

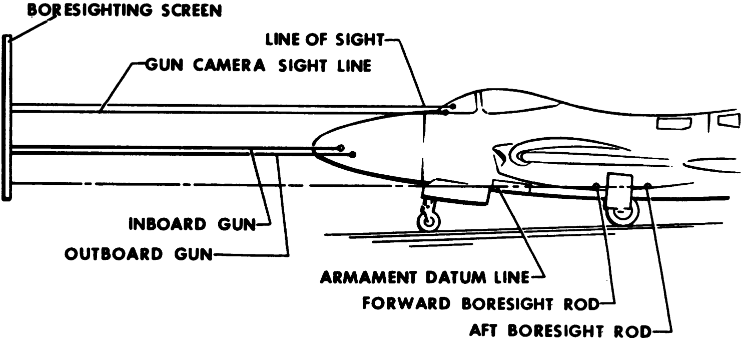


Figure 12–1.—Aircraft boresighting diagram.

reticle below (or above) the pipper by the amount of the sight angle.

SIGHT ANGLE.—The angle between the zero sight line and the line of sight to the impact point at the instant of firing or release. The sight angle is positive when the zero sight line is above (beyond) the impact point and negative when the zero sight line is below (short of) the impact point. The principal factors determining the sight angle are trajectory drop and angle of attack.

ALLOWANCE FOR PARALLAX.—Correction to the sight angle to compensate for the fact that the sight is above the gun, rocket launcher, or bomb station.

GUN BORE LINE.—The centerline of the gun bore. This line is established by a gun boresight instrument provided for this purpose.

LINE OF FIRE.—A line extending through the center of the gun bore and projected out into space.

POINT OF CONVERGENCE.—The distance from the gun where the line of fire and line of sight converge or intersect.

LONG RANGE BORESIGHTING.—A method of boresighting in which a distance object is used as a target, usually located at the point of convergence.

SCREEN BORESIGHTING.—A method of boresighting at short range, using a specially prepared screen as a target.

BORESIGHTING TEMPLATE.—A specially prepared card or screen used as the target in template boresighting.

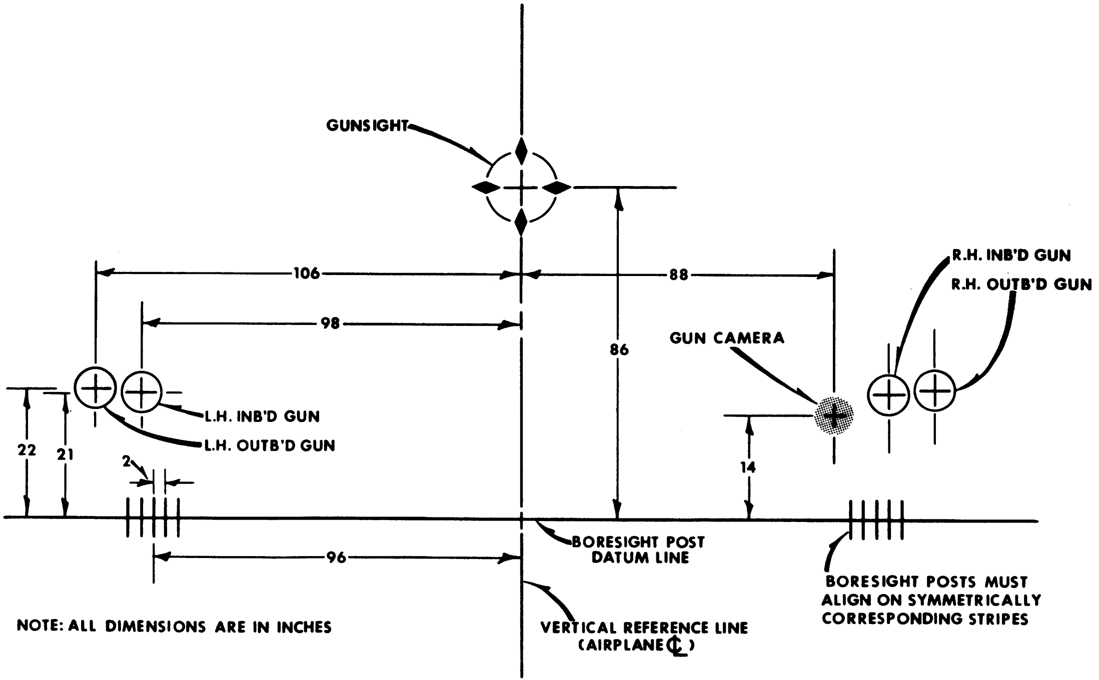

GUNSIGHT
106
88
98
86
GUN CAMERA
R.H. INB'D GUN
R.H. OUTB'D GUN
L.H. INB'D GUN
L.H. OUTB'D GUN
22
21
2
14
96
BORESIGHT POST DATUM LINE
BORESIGHT POSTS MUST ALIGN ON SYMMETRICALLY CORRESPONDING STRIPES
NOTE: ALL DIMENSIONS ARE IN INCHES
VERTICAL REFERENCE LINE (AIRPLANE ℄)

Figure 12-2.—Boresight chart.

Boresight chart.—A diagram or chart showing all the measurements and other information necessary for the construction of a boresight template or screen. (See fig. 12–2.) Boresight charts are supplied by the airplane manufacturers and are available in the *Handbook of Maintenance Instructions* (Erection and Maintenance Manuals) for the aircraft.

Boresight posts (rods).—Attachments which may be fitted in the wing panels (or fuselage of some airplanes), resembling the sights on a rifle, and used in alining the boresight screen or template and the airplane when boresighting forward firing guns. (See fig. 12–3.)

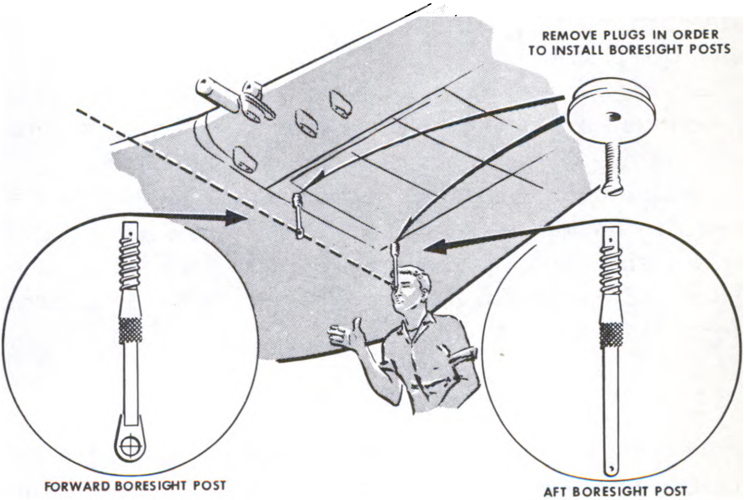


Figure 12–3.—Installation and use of boresight posts.

Boresight kit.—A kit containing optical extensions that can be inserted into the breeches or muzzles of guns mounted in inaccessible places. By sighting through the eyepiece of the sighting extension, the ordnanceman can aline the gun bore with the target just as though he were looking through the gun bore.

Positioning and leveling equipment.—In cases where the horizontal and vertical reference lines are not alined with the boresight brackets or borescope, the aircraft and screen are leveled with a spirit level, quadrant, and leveling bar. The actual leveling is done with mechanical or hydraulic jacks. Tie-down lines are used to hold the aircraft in position. When pad eyes are not available, weights of not less than 500 pounds are used.

ADJUSTING TOOLS.—These include the various hand tools for adjusting the guns, gunsight, gun camera, radar antenna, and tools for opening or removing doors, covers, access holes, and the radome.

GUN CAMERA BORESIGHT LINE.—The camera line of sight.

ROCKET AND BOMB LAUNCHER BORESIGHT LINE.—The line made by the alinement of the aft and forward launcher lugs.

RADAR BORESIGHT LINE.—A line in the direction that the antenna is pointing, when it is in stowed or zero azimuth and elevation position.

ELECTRICAL BORESIGHTING.—Electrical boresighting is the procedure for bringing the radar antenna electrical axis into the parallel relationship with the antenna optical axis.

HARMONIZATION.—Harmonization is the procedure for bringing the antenna or sight unit optical axis into parallel relationship with the aircraft armament datum line. The harmonization instructions usually include the procedures for final zeroing and calibrating.

Parallel Boresighting

Parallel boresighting consists of paralleling all the aircraft's guns, the zero sight line, and the armament datum line in the horizontal plane. In the vertical plane the sight line is sometimes adjusted to converge with the gun bore line at a certain range. This convergence is to compensate for parallax. Parallel boresighting is sometimes called, "infinity boresighting." It is usually used for aircraft that have their guns grouped close together. In modern jet aircraft the wings are thin and the armament is generally mounted in the nose section or around the fuselage. Thus the firepower is fairly well concentrated the full distance from the plane to the maximum effective range of the guns.

Convergence Boresighting

This type of boresighting consists of alining all the guns and the zero sight line so that they converge at a certain range in the horizontal plane. In the vertical plane the sight line is adjusted to converge with the gun bore line at this predetermined range to compensate for parallax. At this range the firepower becomes very concentrated and lethal. If one gun should be misalined, the concentration of firepower is not greatly affected. Convergence boresighting is used for aircraft that have their guns separated, as in wing guns. At times, it is also used for aircraft that use nose guns. The type of aircraft mission will often determine the boresighting. The main disadvantage to convergence boresighting is that the firepower begins to disperse beyond the point of convergence.

A third type of boresighting is pattern boresighting. In this system the guns are alined so that gun bore line for each pair of guns will converge at different ranges. Because it has been found to be less effective than the other types, pattern boresighting is rarely used now.

Methods of Boresighting

Long range method.—The long range boresight method, the guns and sights are adjusted so their axes will bear on a prepared target at a prescribed distance in front of the aircraft. The prescribed distance is where convergence is desired. This method often makes use of a firing range.

The long range method has the advantages of being the most accurate and the fastest method. The disadvantage is that the space required is not always available. This is especially true aboard a carrier.

Screen method.—The screen method uses a fixture having separate aiming points for the sight, individual guns, camera, and boresight brackets. It may be designed for use at any given distance in front of the aircraft. The general layout of a boresight screen is shown in figure 12–2 which actually shows a boresight chart. (The screen is made from the chart.) Screens are very often painted on hangar doors, hangar walls, or bulkheads aboard carriers. Usually the distance from aircraft to screen is from 10 to 50 yards.

The advantages of the screen method are that it may be used where space is limited, and that it may be used over and over for the same type aircraft. The disadvantage is that any error, no matter how small, in alining guns or sight at these short distances is greatly magnified at firing range. For this reason, the screen method is not as accurate as the long range method.

TEMPLATE METHOD.—The template method normally uses a steel frame containing the aiming points for guns and sight on a card or screen. This frame is constructed in such a manner that it can be attached to some part of the aircraft having a fixed relationship to guns and sight. Adjustments are then made so that the guns and sight will bear on these aiming points. This method has also been used in the boresighting of turret guns.

The advantage of the template method is that it may be used where space is very limited. The major disadvantage is that any error at this very short boresight distance will be greatly magnified at the firing range. The template method is not recommended if other methods can be used.

FIXED FORWARD FIRING SYSTEM

The general procedure for boresighting will depend upon squadron doctrine, type of aircraft, space available, mission of squadron, etc. A procedure for a specific aircraft can be found in the *Handbook of Maintenance Instructions* for the aircraft, while detailed procedure for a specific sight can be found in the maintenance manuals for the sight. As an example, let us now consider a procedure for boresighting a typical fixed forward firing system using the screen method of boresighting.

Sequence of Boresighting

Be sure to follow all safety precautions while boresighting. One sequence used in a boresighting procedure is:

1. Aircraft preparation.

2. Aircraft and screen alinement.
3. Sight alinement.
4. Boresighting of sight unit.
5. Radar antenna alinement.
6. Alinement of guns.
7. Alinement of gun camera.
8. Rocket launcher alinement check.

Aircraft preparation is the first step, regardless of sequence followed. All arming and firing switches must be in the OFF position, and the ammunition cleared from the guns. All the necessary doors, covers, and access holes should be opened or removed. The gun blast tubes and nose pieces should be removed, if necessary. The guns and gun camera should then be made ready for boresighting. The boresight rods, posts, or peepsight tubes should be installed in the boresight fixture on the airplane.

When the aircraft is located the prescribed distance from the screen, the wheels should be chocked. Then jack the airplane using the jack points on the wing and fuselage. The purpose of jacking the airplane is to take the weight off the shock struts, as movement of personnel climbing into the aircraft to make sight adjustments may change the airplane's attitude. Jacking also helps to aline the airplane with the target should the target be painted on a wall or bulkhead and not adjustable.

The aircraft is then leveled using a spirit leveling device. At this approximate flight attitude, the aircraft and screen should be alined.

Aircraft and Screen Alinement

The requirements for aircraft and screen alinement are: (1) the correct range between screen and aircraft, (2) the armament datum line be alined with its aiming point on the screen, and (3) the aircraft and screen have the same horizontal and vertical references. To satisfy these requirements, either the following or a similar procedure is followed:

1. Keep the boresighting area clear of traffic between the aircraft and screen.

2. If possible, mount the screen on a movable stand (portable hydraulic lift) in order that it may be moved forward and back, laterally, or raised and lowered slightly.

3. If a stand is not available, the screen should be secured to the hangar, bulkhead, or some other suitable support.

4. The aircraft should now be in position facing the screen.

5. Position the screen the proper distance from the aircraft. Of course, if the screen is painted on a wall or bulkhead, the positioning is accomplished by movement of the aircraft.

6. Shift the screen horizontally until the aircraft's vertical reference is the same as the screen's vertical reference. Check to insure that the aircraft and screen horizontal lines are alined.

7. Move the target screen vertically until the armament datum line of the aircraft is alined with the armament datum line on the boresight screen. The line thus established is parallel to the line of flight of the airplane under prescribed operating conditions. These operating conditions are given in the aircraft's maintenance instructions.

The boresight screen (or as sometimes called, panel) is made in accordance with instructions given on the boresight chart in the maintenance manuals. Plywood or any suitable material may be painted to provide a white background. The aim points for the guns, gunsight, gun camera, and reference lines are then painted in red or black paint.

If a range other than the one indicated on the chart is to be used for boresighting, all dimensions must be checked to insure accurate boresighting. Parallel boresighting without correction for parallax requires no changes. With parallax correction, only the vertical distances between gun aiming points and the boresight datum line normally need to be recomputed. This distance will vary as the distance between the plane and the screen changes. For example, a chart contains a dimension of 90 inches at a distance of 1,000 inches. It is desired to use a distance of 360 inches (30 feet). What is the new dimension for use on the boresight screen?

$$\frac{360}{1{,}000}\times 90=32.4$$

Thus, 32.4 inches instead of 90 inches.

Planes using point convergence boresighting of wing guns require recomputation of the horizontal dimensions in addition to those dimensions mentioned above. The horizontal distances will vary inversely as the distance between the screen and the plane.

Regardless of range, the vertical plane of the boresight screen must be maintained perpendicular to the aircraft's armament datum line.

Alinement and Harmonization

Once the screen and aircraft have been alined, the boresighting of the gunsight, guns, gun camera, and rocket launchers may be accomplished. Normally the AQ will boresight the sight unit and mechanically boresight the radar antenna, while the guns and rocket launchers are alined by the ordnance men.

Prior to boresighting, the sight unit's optical parallax and alinement must be checked. The check for parallax was discussed in the chapter concerning the sight units. If the amount of parallax is not within the specification limits for the particular sight unit, it must be replaced. Alinement of a computing sight unit is the alinement of the fixed and gyro reticle images. Some sight units have the means of EXTERNALLY adjusting this alinement. Let us consider the alinement and boresighting of one of these sights—Sight Unit Mk 8.

ALINEMENT.—To aline the Sight Unit Mk 8 proceed as follows:

1. Obtain an optical gage (Navy Stock No. J942–G–315) and attach it to the sight unit.
2. Set the SELECTOR switch to the FIXED & GYRO position and adjust the DIMMER knob until both images are properly illuminated.
3. While looking through the optical gage, gradually move the ranging grip from minimum to maximum range and note the movement of the gyro pipper in relation to the fixed cross.

If the gyro pipper does not coincide with the center of the fixed cross at any range, an adjustment should be made.

4. Move the ranging throttle grip until the center gyro pipper is located midway between the two extremities of its travel.

5. Unscrew the silica gel cell mounting screw and remove the cell from the sight unit.

6. Position the fixed cross so that its center coincides with the center gyro pipper by adjusting the two fixed mirror adjusting screws which project from the back plate of the gyro unit. The fixed cross is moved horizontally by adjusting the upper screw and vertically by adjusting the lower screw.

7. Replace the gel cell, making sure that the gel cell gasket is properly positioned. Do not tighten the mounting screw excessively.

8. Remove the optical gage.

Boresighting the sight unit.—The procedure for boresighting the Sight Unit Mk 8 (note that the fixed reticle image is used) is as follows:

1. Set the SELECTOR switch to the FIXED position.

2. Note the position of the cross of the image relative to the boresight target point.

3. If the center of the cross does not coincide with boresight target point in azimuth, loosen the sight unit mounting bolt and rotate the sight unit and the azimuth adjusting ring until the center of the cross of the fixed reticle image is directly on the boresight target point within plus or minus 0.85 mil.

4. Tighten the sight unit mounting bolt after the azimuth boresight adjustment has been completed.

5. If the center of the cross does not coincide with the boresight target point in elevation, adjust the elevation boresighting fittings. The elevation fittings are part of the aircraft mounting attachment.

Harmonization of radar antenna.—The procedure for alining the antenna optical axis parallel with the armament datum line is as follows:

1. Turn the radar master switch to the OFF position.

2. Remove the radome.

3. Install the appropriate telescope on the antenna adapter.

4. Position the antenna in its zero azimuth and elevation position. On some radar equipment, locking pins are provided for the zero position.

5. Loosen the antenna adjusting bolts. ***Caution:*** Do not disturb the antenna reflector adjustments.

6. Adjust the antenna until the cross hairs of the boresighting fixture are alined with the radar antenna aiming point on the screen.

7. Tighten the antenna adjusting bolts. Check the alinement again for movement after tightening the adjustment bolts.

8. Remove the boresighting fixture (telescope and adapter) and replace the radome.

BORESIGHTING GUNS.—The procedure for boresighting the guns is as follows:

1. Make certain that all guns are clear of ammunition.

2. Insert the muzzle adapter in the muzzle of the gun.

3. Insert eyepiece using necessary angles and attachments (use the designated boresighting kit).

4. Bring the guns on to the proper markings on the screen by turning the adjustment nuts of the gun mounts.

5. Lock the adjustment nut with the locknut and remove the boresight tool.

BORESIGHTING THE GUN CAMERA.—The procedure for boresighting the gun camera is as follows:

1. Remove the magazine from the camera.

2. Insert type AN–1 gun camera boresighting tool in the camera.

3. Loosen the camera horizontal and vertical adjustments.

4. Open the camera shutter.

5. Adjust the camera until the cross hairs of the gun camera boresight tool are alined with the gun camera aiming point on the screen.

6. Tighten the camera adjustments and then recheck the alinement.

7. Remove the boresighting tool and replace the magazine.

The procedure for boresighting and harmonizing a turret system is very similar to that used in the forward firing system. Once again, the *Handbook of Maintenance Instructions* for the aircraft contains the needed information. The manual for the turrets and turret sights also includes boresighting information. As in the forward system, these procedures may be modified by squadron doctrine.

Long distance boresighting of turret systems is the most accurate, but the screen method is often used. In the long distance system, the bore line of the guns and the line of sight converge on a target 1,000 yards or more away.

As an example for boresighting a typical turret system, let us consider a top deck turret using a Gunsight Mk 18. It should be pointed out that boresighting in reference to a turret system is the operation necessary to provide parallelism of the two gun bore lines and to establish the guns in correct relationship with the turret. Harmonization is the process of adjusting the line of sight parallel with the two bore lines after the guns have been boresighted.

BORESIGHTING GUNS.—To boresight the guns of a deck turret proceed as follows, using figure 12–4:

1. Level the airplane.
2. Rotate the turret to the position shown in figure 12–4. With the gun cradles at zero elevation, insert the elevation locking pins.
3. Place a spirit level on each gun barrel. Level the gun if necessary by loosening the locknut under the aft trunnion.
4. Toe each gun out laterally as far as possible by loosening the locknut.
5. Place a borescope or other sighting device in each gun barrel.
6. Erect and adjust a boresight screen so the gun aiming points are level with the gun bore lines.
7. Move the turret in azimuth so each gun bore line is approximately the same distance outboard of its respective aiming point.

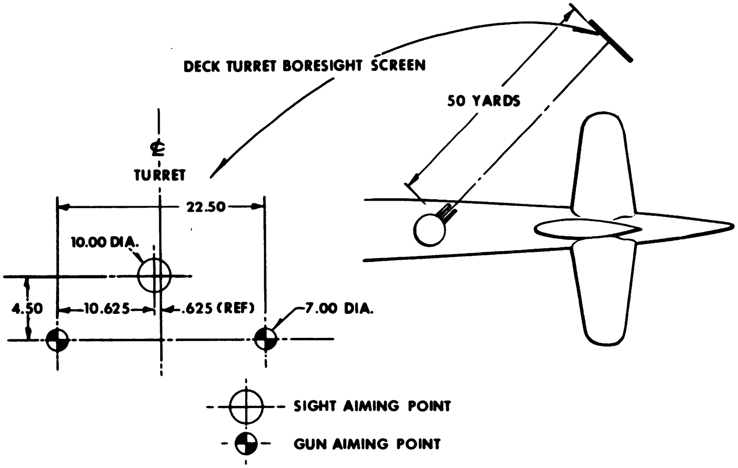


Figure 12–4.—Deck turret boresighting.

8. Adjust the aft trunnions laterally so the gun bore lines coincide with gun aiming points.

Harmonizing the sight and guns.—Before undertaking the following procedure, the sight must be alined. The procedure for alining the Gunsight Mk 18 is the same as that used for the Sight Unit Mk 8. To harmonize the sight and guns, proceed as follows:

1. Turn the selector switch to FIXED and adjust the dimmer knob until the fixed cross reticle appears clearly defined on the combining glass of the sight head.

2. Loosen the center bolt in the bottom of the sight mounting bracket and turn the sight unit so that the center of the fixed cross is in vertical alinement with the sight aiming point of the boresight screen.

3. Tighten the center bolt and recheck to make certain the adjustment was not disturbed during the tightening.

4. Adjust the sight mounting bracket in elevation to bring the fixed cross precisely upon the sight aiming point on the boresight screen. The elevation fittings are part of the aircraft mounting attachment.

QUIZ

1. The AQ3 will normally be responsible for boresighting the
   - a. sight and radar antenna mechanically
   - b. sight and radar antenna electrically
   - c. sight, gun, gun camera, and rocket launchers
   - d. sight only
2. The purpose of boresighting is to
   - a. determine the flight attitude of the aircraft
   - b. eliminate parallax
   - c. compensate for the trajectory of the projectile due to gravity
   - d. establish a relationship between the line of sight and the line of fire
3. The flight line of an airplane is
   - a. always the same for a particular type aircraft
   - b. a line in space parallel to the armament datum line
   - c. a line in space parallel to the gun bore line
   - d. the line in space along which the airplane is moving
4. The armament datum line is
   - a. used when boresighting turrets only
   - b. used as a reference in boresighting
   - c. established by the man boresighting the airplane
   - d. parallel to the flight line
5. The first step in boresighting an aircraft is
   - a. aircraft alinement
   - b. sight alinement
   - c. gun alinement
   - d. aircraft preparation
6. In modern jet aircraft the type of boresighting most often used is
   - a. pattern
   - b. convergence
   - c. parallel
   - d. screen
7. Convergence boresighting is used
   - a. whenever rockets are to be fired
   - b. for aircraft that have their guns mounted close together
   - c. for aircraft that have their guns separated
   - d. for turrets only

8. The three methods of boresighting in their order of accuracy are
   a. long range method, screen method, template method
   b. screen method, long range method, template method
   c. long range method, template method, screen method
   d. template method, long range method, screen method

9. The advantage of the template method of boresighting is that it
   a. is the fastest method
   b. is very accurate
   c. may be used where space is very limited
   d. requires only one person to boresight the airplane

10. The correction to the sight angle to compensate for the fact that the sight is above the gun is called
   a. sight angle
   b. allowance for parallax
   c. point of convergence
   d. angle of attack

11. The sight unit's optical parallax and alinement should be checked
   a. either prior to or after boresighting
   b. at any time during boresighting
   c. prior to boresighting
   d. after boresighting

12. If the amount of parallax is not within the specified limits for a particular sight unit, it should be
   a. replaced
   b. adjusted
   c. boresighted and then checked for parallax again
   d. corrected by replacing the silica gel cell

13. When making the alinement check on the Sight Unit Mk 8, if the gyro pipper does not coincide with the center of the fixed cross at any range,
   a. the silica gel cell should be replaced
   b. the sight unit should be replaced
   c. the speed of the gyro motor is not correct
   d. an adjustment should be made

14. When boresighting a sight unit, the ________________ is (are) used.
   a. gyro and fixed image
   b. gyro image
   c. fixed image
   d. gyro or fixed image

15. **When using the long distance method to boresight a turret, the bore line of the guns and the line of sight converge at a distance of**
    - a. **1,000 feet or less**
    - b. **500 yards**
    - c. **2,000 feet**
    - d. **1,000 yards or more**

CHAPTER 13

SAFETY PRECAUTIONS

The problems of SAFETY PRECAUTIONS are of major concern to the Navy. Recognizing the need for one central and authoritative publication for ready reference, the Navy published *United States Navy Safety Precautions*, OpNav 34P1. This publication contains "those safety precautions which will be instrumental in avoiding preventable accidents and in maintaining a work environment which is conducive to good health." Included in this publication is the following quotation from the "Basic Rule of Responsibility" of the section on "Basic Precepts":

"3. **Operating Personnel.** Each individual concerned shall strictly observe all safety precautions applicable to his work or duty.

a. REPORTING UNSAFE CONDITIONS. Each individual concerned shall report any unsafe condition, or any equipment or material which he considers to be unsafe.

b. WARNING OTHERS. Each individual concerned shall warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.

c. PERSONAL PROTECTIVE EQUIPMENT. Each individual concerned shall wear or use protective clothing or equipment of the type approved for the safe performance of his work or duty.

d. REPORT OF INJURY OR ILL HEALTH. All personnel shall report to their supervisors any injury or evidence of impaired health occurring in the course of work or duty.

e. EMERGENCY CONDITIONS. In the event of an unforeseen hazardous occurrence each individual concerned is expected to exercise such reasonable caution as is appropriate to the situation."

HANDLING PORTABLE TOOLS

Hand Tools

Basically, safety is a commonsense approach to whatever is being done, at leisure time as well as during working hours. If a person knows his job and the factors involved, and does the job in the safest possible manner, very little is left to chance. The more factors involved the more difficult is the problem of safety. An Aviation Fire Control Technician has to work with aircraft, tools, machinery, electrical and electronic equipment, and armament equipment. The combined potential danger of these leaves the AQ with minimum room for chance. He must know what is to be done and how to do it safely and properly.

As a general precaution, be sure that all tools used conform to Navy standards as to quality and type, and use them only for purposes for which they were intended. All tools in active use should be maintained in good repair, and all damaged or nonworking tools should be returned to the toolkeeper. Be particularly careful NEVER to leave tools adrift in an aircraft. When a job is completed, remove all of the tools.

Use only straight, undamaged, and properly sharpened DRILLS. Tighten the drill securely in the chuck using the key provided and never with wrenches or pliers. It is important that the drill be set straight and true in the chuck. The work should be firmly clamped and, if of metal, a center punch should be used to score the material before the drilling operation is started.

Care should be taken in selecting the correct type of PLIERS, SIDE CUTTERS, OR DIAGONAL CUTTERS. Pliers or cutters should not be used on nuts or pipe fittings. When cutting short pieces, take care that they do not fly and cause injury. The fingers should not be wrapped around the handle of a tool in such a way that they can be pinched or jammed if the tool slips from the work. The use of extensions on the tool handle to increase leverage is prohibited.

In selecting a SCREWDRIVER for electrical work, be sure that it has a nonconducting handle. The screwdriver should not be used as a substitute for a punch or a chisel, and care should be taken that one is selected of the proper size to fit the screw. The point of the screwdriver should be kept in proper shape with a file or a grinding wheel.

Use WRENCHES only if they are in good condition and are right for the job. Never use a wrench as a hammer and do not put an extension on the handle. An adjustable wrench should be faced so that the movable jaw is located forward in the direction in which the handle is to be turned. When working in a confined space, the worker should take care that the grip he uses will not endanger him.

When working with sharp hand tools, always work so that the tools are moved or thrust away from the body.

Portable Power Tools

All portable power tools should be carefully inspected before being used to see that they are clean, well-oiled, and in a proper state of repair. The switches should operate normally, and the cords should be clean and free of defects. The casings of all electrically driven tools should be grounded. Sparking portable electrical tools should not be used in any place where flammable vapors, gases, liquids, or exposed explosives are present.

Be sure that power cords do not come in contact with sharp objects. The cords should not be allowed to kink, nor be left where they might be run over. They should not be allowed to come in contact with oil, grease, hot surfaces, or chemicals; and when damaged, should be replaced instead of being patched with tape.

When using a portable power drill, grasp it firmly during the operation to prevent it from bucking or breaking loose, thereby causing injury to yourself or damage to the tool.

When required, safety-shield goggles, gloves, and other safety clothing must be properly worn. It is a good procedure to use rubber gloves, matting, or other insulated decking to eliminate the dangers of a possible insulation failure.

WORKING WITH MACHINERY

In addition to the general precautions on the use of tools, there are a few other precautions which should be observed when you work with machinery. The more important ones are listed below:

1. Never remove a guard or cover from a running machine.
2. Never operate mechanical or powered equipment unless you are thoroughly familiar with its controls. When in doubt, consult the appropriate instruction pamphlet or ask someone who knows.
3. Always make sure that everyone is clear before starting or operating mechanical equipment.
4. Never try to clear jammed machinery without first cutting off the source of power.
5. When hoisting heavy machinery (or equipment) by a chain fall, always keep everyone clear, and guide the hoist with lines attached to the equipment.
6. Never plug in portable electric machinery without insuring that the source is the kind of electricity (a. c. or d. c.) called for on the nameplate of the machine.

ELECTRICAL AND ELECTRONIC WORK

Accident potentials such as aircraft propeller, jet exhaust, spilled liquids, and some vapors can be detected by the senses. Electrical circuits cannot be so detected. A person cannot safely tell a live dangerous circuit from an unenergized harmless circuit by his senses alone. The only protection against electrical shock is by following adequate safety precautions.

Personal Protection

Because of the possibility of injury to personnel, the danger of fire, and possible damage to material, all repair and maintenance work on both electronic and electrical equipment should be done ONLY by a duly authorized and assigned person.

When any electronic equipment is to be overhauled or worked on, the main supply switches or cutout switches in each circuit from which power could possibly be fed should be secured in the open position and tagged. The tag should read: "This circuit was ordered open for repairs and shall not be closed except by direct order of . . . " (usually the person directly in charge of the repairs). After the work has been completed, the tag (or tags) should be removed by the SAME PERSON.

Do not work on any type of electrical apparatus with wet hands or while wearing wet clothing, and do not wear loose or flapping clothing. The use of thin-soled shoes with metal plates or hobnails is prohibited. Safety shoes with nonconducting soles should be worn if available. Flammable articles, such as celluloid cap visors, should not be worn.

When working on electronic or electrical apparatus, technicians should first remove all rings, wristwatches, bracelets, and similar metal items. Care should be taken that the clothing does not contain exposed zippers, metal buttons, or any type of metal fastener.

You should never touch electrical conductors while the circuit or equipment is energized. NEVER take a shock intentionally.

Caution: Better than 50 percent of the fatalities by electrical shock aboard ship were caused by circuits of 115 volts or less.

Protective Equipment

Besides following personal safety precautions, technicians should always make the proper use of protective equipment. Where possible, rubber mats and gloves should be utilized.

The covers of fuse boxes and junction boxes should be kept securely closed except when work is being done on them. Safety devices, such as interlocks, overload relays, and fuses, should never be altered or disconnected except for replacements. Safety or protective devices should never be changed or modified in any way without specific authorization.

Fuses should be removed and replaced only after the circuit has been completely deenergized. When a fuse blows, it should be replaced only with a fuse of the same current rating. When possible, the circuit should be carefully checked before making the replacement, since the burned-out fuse is often the result of circuit fault.

Before touching a capacitor which is connected to a deenergized circuit, or which is disconnected entirely, the terminals should be short-circuited to make sure that the capacitor is completely discharged. Grounded shorting prods should be permanently attached to workbenches where radar equipment and other types of electronic devices are regularly serviced. Once again, do not disable capacitor shorting devices used in some equipments.

General Electronic Safety

ENERGIZED CIRCUITS.—Insofar as is practicable, repair work on energized circuits should NOT be undertaken. When repairs on operating equipment must be made because of emergency conditions, or when such repairs are considered to be essential, the work should be done only by experienced personnel, and if possible, under close supervision. Every known safety precaution should be carefully observed. Ample light for good illumination should be provided; and the worker should be insulated from ground with some suitable nonconducting material, such as several layers of dry canvas, dry wood, or a rubber mat of approved construction. The worker should, if possible, use only one hand in accomplishing the necessary repairs. Helpers should be stationed near the main switch or the circuit breaker so that the equipment can be deenergized immediately in case of emergency. A man qualified in first aid for electric shock should stand by during the entire period of the repair.

HIGH-VOLTAGE PRECAUTIONS.—Personnel should never work alone near high-voltage equipment. Tools and equipment containing metal parts, such as brushes and brooms, should not be used in any area within four feet of high-voltage circuits or any electric wiring having exposed surfaces. The handles of all metal tools, such as pliers and cutters, should be covered with rubber insulating tape. (The use of plastic or cambric sleeving or of friction tape alone for this purpose is prohibited.)

Warning signs and suitable guards should be provided to prevent personnel from coming into accidental contact with high voltages.

Transmitter adjustments should not be made while the equipment is energized unless the adjustments can be accomplished from the front control panel or other external source. Similar precautions should be taken with oscilloscope circuits, which employ voltages corresponding to those used in radar transmitting equipments.

Electric detonators.—Certain types of electric detonators can be fired by the action of radiofrequency energy. All electric detonators, or igniters, and also electrically fired rocket motors and electric ordnance fuzes, should never be exposed or located within five feet of any type of transmitting equipment, including antennas and antenna leads. No danger due to radiofrequency potentials exists, however, with detonators of any type while they are enclosed in covered metal containers.

Volatile liquids.—Volatile liquids, such as insulating varnish, lacquer, turpentine, and kerosene, are dangerous when used near electronic equipment which is operating because of the danger of igniting the fumes by sparks. When these liquids are used in compartments containing nonoperating equipment, be sure that there is sufficient ventilation to avoid an accumulation of fumes and that all fumes are cleared before the equipment is energized.

Alcohol should never be used for cleaning in locations where a spark is possible, neither should carbon tetrachloride be employed as a cleaning agent. Unlike alcohol, the use of carbon tetrachloride does not create a fire hazard; but it is dangerous because of the injurious effects of breathing its vapor. The careless use of carbon tetrachloride may result in headache, dizziness, and nausea. If the fumes are breathed in poorly ventilated compartments, the effect may be a loss of consciousness or even death. For these reasons, the use of carbon tetrachloride as a solvent or cleaner has been specifically prohibited in Navy maintenance operations. When cleaning electrical or electronic equipments or parts, always use the approved cleaning agent, Dry Cleaning Solvent, Federal Specification PS–661.

ELECTRICAL FIRES.—In case of electrical fires, the following steps should be taken:

1. Deenergize the circuit.
2. Call the Fire Department if the fire is in a hangar or a shop.
3. Control or extinguish the fire, using the correct type of fire extinguisher.
4. Report the fire to the appropriate authority.

For combating electrical fires, use a CO_2 (carbon dioxide) fire extinguisher and direct it toward the base of the flame. Carbon tetrachloride should never be used for fire fighting since it changes to phosgene (a war gas) upon contact with hot metal, and even in open air this gas creates a hazardous condition. The application of water to electrical fires is dangerous; and foam-type fire extinguishers should not be used since the foam is electrically conductive.

In case of cable fires in which the inner layers of insulations or insulation covered by armor are burning, the only positive method of preventing the fire from running the length of the cable is to cut the cable and separate the two ends.

SELENIUM RECTIFIERS.—When selenium rectifiers burn out, fumes of selenium dioxide are liberated which cause an overpowering stench. The fumes are poisonous and should not be breathed. If a rectifier burns out, deenergize the equipment immediately and ventilate the compartment. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the equipment containing it out of doors. Do not touch or handle the defective rectifier while it is hot since a skin burn might result through which some of selenium compound could be absorbed.

DISPOSITION OF RADIOACTIVE TUBES.—Useless unbroken tubes containing radioactive material, such as spark gap, TR, glow lamp, or cold cathode-ray tubes, should be treated as any other radioactive waste material. They should be sunk intact at sea. In shore installations it is best to collect the tubes in special containers which should be weighted, sealed, and shipped out to be sunk at a convenient time. A plot of land may be set aside near the shore station to be used as a burial ground. However, the former method of sinking is recommended. If a burial plot is used, it should be adequately posted and supervised.

Any equipment or tools used in crushing tubes or handling radioactive junk should be thoroughly cleaned before using for other purposes, or, if practicable, such equipment and tools should also be buried or sunk at sea. It should be borne in mind that any buried material may at some later date be exposed by land excavation and cause radioactive poisoning exposures.

Handling Cathode-Ray Tubes

The trend toward the use of large cathode-ray tubes has increased the dangers of implosion, or collapse of the glass tubes as a result of atmospheric pressure. The tubes are not dangerous if properly handled; but if they are struck, scratched, dropped, or handled carelessly in any way, they can very well become an instrument of severe injury or death. The following precautions should be taken for the protection of personnel:

1. Wear goggles to protect the eyes from flying glass particles which result from implosion due to fracture of the envelope. The goggles should be of the type which provide side and front protection and which have clear lenses that can stand a rigid impact test.

2. Wear suitable gloves to protect the hands.

3. Be sure that no part of the body is directly exposed to possible glass splinters caused by implosion. Also remember that the coating on some tubes is poisonous if absorbed into the blood stream.

4. Care of the tube. Do not expose the tube to possible damage. When the tube is needed, remove it from the packing box with caution, taking care not to strike or scratch the envelope. Insert it into the equipment socket cautiously, using only moderate pressure. Do not jiggle the tube. Use

the same precautions when removing the tube from the equipment.

When the tube must be set down, it is important that the face be placed on a clean, soft padding. Do not stand directly in front of the face, for an accidental implosion may cause it to be propelled directly forward with a velocity sufficient to cause severe injury.

Working on Antennas

Although the AQ is not required to maintain radio transmitters and their antennas, he will work near them at times. An energized antenna always presents the danger of a RF burn or of the RF burn causing personnel to fall from the aircraft or to drop expensive equipment. The movement of a radar antenna, which has the radome removed, can also result in injury to personnel or damage to other equipment, such as test equipment. Since the antenna of airborne fire control radars are precision pieces of equipment and easily damaged, precautions must be taken to insure their safety and accuracy. Some of the safety precautions for working on or near antennas are:

1. When working on the fire control radar antenna, stay clear of other antennas.
2. Never force a radar antenna by hand, for this action may damage the antenna drive or indicating system.
3. Always check, and remove if necessary, the antenna's zero elevation and azimuth locking pins prior to operation and prior to replacing the radome.
4. If the antenna is part of a radar controlled turret system, stay clear of the guns and the gun's line of fire. Always personally check the guns to insure they are clear of ammunition.

OPERATING AVIATION FIRE CONTROL EQUIPMENT

The equipment handbooks contain detailed safety precautions for the operation of aviation fire control equipment. These precautions must be followed for the safety of the equipment as well as the safety of the personnel. The general safety precautions for armament control, bombing, and turrets are similar in most respects.

The safety precautions around aircraft, as just discussed, must be followed whether working on the equipment or operating them. Some additional safety precautions for operating fixed, forward firing control systems are:

1. Aircraft with loaded guns or live stores should be pointed away from other aircraft, hangars, and other personnel if at all possible. Guns should not be armed when personnel are working on equipment. You should check to insure that there is no ammunition in guns before beginning to work on an aircraft.

2. Never operate the equipment during fueling or defueling operations.

3. Never turn on the battery or power switches to the equipment without insuring that the arming and firing switches for the guns or stores are in the OFF position.

4. Before applying power to the equipment, the area must be clear of flammable materials.

5. Check with the pilot before energizing the equipment when airborne.

When airborne, remember that the pilot in command of the aircraft is responsible for the safe and orderly conduct of the flight. When the AQ wishes to operate any equipment or make any unusual repairs on the equipment, he must always request permission from the pilot before proceeding.

Besides these precautions, the following must also be followed in the operation of radar controlled turrets:

1. Never operate the turret until all personnel, tools, locking pins, and obstructions are clear.
2. Check the turret structural limit stops before operating the turret at high speed.
3. Never slew the turret unnecessarily.
4. Keep hands and clothing clear of turret drive system.
5. Do not work alone on a turret.

It should be remembered that safety depends on the individual. The manner in which he accomplishes his job and how closely he adheres to safety precautions will determine the degree of safety enjoyed by himself and his fellow workers.

ELECTRIC SHOCK

Persons suffering from electric shock are often unconscious; the pulse is feeble and irregular and the breathing is slow and faint. The parts of the body that have come in contact with a live wire are sometimes burned or blistered.

The first, and most important thing to do for a person who has been shocked is to REMOVE THE PERSON from contact with the electric circuit or machine, or to cut the power supply. Disconnecting the power is the best bet if the power switch is located near the scene of the accident. However, in the event that cutting the power will waste time, you must remove the victim from contact with the circuit. This is always dangerous and should not be attempted until some means of insulating yourself is available. Your hands should be protected with rubber if possible, or several thicknesses of dry cloth. You should be further insulated by standing on a rubber mat if one is available at the scene, a pane of glass, or a dry board.

At the first opportunity, while you are making preparation to administer first aid, SEND FOR MEDICAL ASSISTANCE.

Artificial Respiration—Burns

For complete coverage of how to administer artificial respiration and how to treat burns, see *Standard First Aid Training Course*, NavPers 10081.

QUIZ

1. The responsibility for safe work practices and accident prevention rests with
   a. every individual concerned
   b. the job supervisor
   c. the senior crew member
   d. the safety officer
2. When using a portable power drill, what is necessary to prevent it from bucking or breaking loose?
   a. A ground connection
   b. An antibucking attachment
   c. Grasping the drill firmly
   d. A power damper
3. When it is necessary to perform inflight maintenance, operation, or unusual adjustments, who may authorize these?
   a. The plane captain
   b. The radio operator
   c. The navigator
   d. The plane commander
4. The accident potential of a live electrical circuit differs from that of such things as aircraft propellers, spilled liquids, etc. in that it
   a. is not dangerous below 1,000 volts
   b. is not dangerous to life
   c. cannot safely be detected by the senses
   d. will kill instantly
5. Whenever circuit breakers, fuses, main power switches, or bus bars are open for repairs, who should remove the tags indicating the open circuit?
   a. A member of the repair crew
   b. The same person who placed the tags
   c. The job inspector
   d. The repair crew leader
6. Carbon tetrachloride is prohibited in Navy maintenance operations because it
   a. is highly inflammable
   b. is injurious to breathing
   c. causes skin disorders
   d. dissolves electrical insulation

7. The best type of fire extinguisher to use on an electrical fire is
    a. fog foam
    b. carbon dioxide
    c. soda acid
    d. salt water
8. The recommended procedure for disposing of radio active material or tools is
    a. incineration (burning)
    b. burial at a depth of 50 feet or more
    c. scattered over a wide area of an uninhabited place like a swamp
    d. burial intact at sea if possible
9. The handling of a cathode-ray tube can be very dangerous due to its
    a. ability to store a large electric charge
    b. screen and some parts being radio active
    c. being filled with a harmful gas
    d. possible implosion and possible flying glass
10. In the event of an accident involving injury to a person by electrical shock, the first thing to do would be to
    a. administer first aid
    b. inform immediate superior
    c. remove the person from contact with the electrical circuit
    d. send for medical assistance

CHAPTER 14

PUBLICATIONS, REPORTS, LOGS, AND FORMS

There are many publications utilized in the proper maintenance of aviation fire control equipment. Technical publications issued by the various bureaus of the Navy Department are sources of important information for every man in the Navy. Publications by the Bureau of Aeronautics, Bureau of Ordnance, and Bureau of Naval Personnel concern Aviation Fire Control Technicians. The most important publications from these sources with which the AQ striker and petty officer should be familiar are discussed in this chapter. But before considering these technical publications, let us discuss the general directive system used throughout the Navy.

INSTRUCTIONS AND NOTICES

A system is in use throughout the Navy for the issuance of directive-type releases including those which prescribe policy, organization, methods, or procedures, and those which contain information. Certain publications, such as established manuals, operational releases, technical publications, some classified matter, and those joint Army-Navy-Air Force publications which are numbered serially, and not having separate Army or Air Force designations, are excluded from the system.

This program is called the Navy Directives System and provides a uniform plan for issuing and maintaining directives. Conformance to the system is required of all bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan: Instructions and Notices.

Instructions are directives which contain information or require action of a continuing nature. An Instruction has permanent reference value and is effective until the originator supersedes or cancels it.

Notices are directives of a one-time nature and contain information or require action which can be completed immediately. A Notice does not have permanent reference value and contains provisions for its own cancellation.

For reasons of identification and accurate filing, all directives can be recognized by the originator's authorized abbreviation, the type of release (whether an Instruction or Notice), a subject classification number; and in the case of Instructions only, a consecutive number. Because of their temporary nature, the consecutive number is not assigned to Notices. This information is assigned by the originator and is placed on each page of the release.

The manner of numbering and identifying directives can be better understood by considering a typical identifier:

SECNAV	INST.	5215.1
(a)	(b)	(c) (d)

(a) Here the authorized abbreviation of the originator of the directive is placed.

(b) This part refers to the type of release, in this case an Instruction.

(c) This is the subject number which is determined by the subject matter of the directive and is obtained from the Table of Subject Classification Numbers.

(d) Following the period is the consecutive number which is found only on Instructions. An originator would assign consecutive numbers to those consecutive instructions with the same Subject Classification Number. In the example above the subject Classification Number 5215 concerns "Issuance Systems." If the originator, SECNAV, issued additional Instructions dealing with issuance systems they would be assigned number 5215.2, 5215.3, 5215.4, etc. Subject classification numbers are listed in the Table of Subject Classification Numbers found in SECNAV Instruction 5215.1. This table contains a numerical and alphabetical listing of numbers with their related subjects, and is of considerable value for reference use when information or instructions, of a particular nature are desired. This Instruction contains all necessary information concerning the use and procedures of the Navy Directives System.

BUREAU OF AERONAUTICS PUBLICATIONS

Bureau of Aeronautics Manual

The *Bureau of Aeronautics Manual* consists of general policy information and instructions concerning matters under the cognizance of the Bureau of Aeronautics. The manual is published to give assistance and guidance in regard to general information of a permanent nature, and it is not intended to lay down detailed instructions which are normally covered by various field directives and other existing instructions. The manual also contains information on publications and data issued by authority of the Chief of the Bureau of Aeronautics. While this information is essentially general in nature, it can be used as an aid in obtaining detailed information.

Naval Aeronautic Publications Index

The *Naval Aeronautic Publications Index* (commonly called *NavAer Publications Index*) is a consolidated listing of all publications and forms which pertain to aeronautical activities. It is divided into three parts:

Part I—Numerical listing of all effective BuAer publications;
Part II—Table of publications relating to aircraft and equipment; and
Part III—Aircraft application list.

Complete instructions for ordering all the publications listed are included in the *Index*. It is issued annually and revisions are published at periodic intervals during the year.

Handbooks

Aircraft maintenance handbooks.—This type of publication is intended to provide information which will aid in the maintenance of aircraft. Information is presented as to location, function, operations, removal, installation, testing, adjusting, and troubleshooting of components. Maintenance methods recommended are concerned with procedures which can be accomplished by operating units.

Before attempting any new task on an aircraft, such as removing a radome, the *Handbook of Maintenance Instructions* for that particular aircraft should be consulted. By proper use of these handbooks possible damage will be prevented and much time may be saved. These handbooks are so arranged that the sections may be removed and kept available in the shop. As an Aviation Fire Control Technician, you will probably be interested in the following sections: Section VII, Electrical Systems; Section VIII, Radio and Radar; Section IX, Armament Systems; and Section X, Wiring Data.

Equipment handbooks.—The Bureau of Aeronautics prepares *Handbooks of Operating Instructions* (HOI) and *Handbooks of Service Instructions* (HSI) for the Armament Control Systems. The HOI's cover the operation of the ACS as a complete system. The HSI's include a limited amount of maintenance information. For detailed operation or maintenance information the system handbook refers to the individual HOI or HSI for the radar, the BuOrd AFCS, or the Aero armament component as appropriate.

For each of these electronic equipments (radars), four handbooks are prepared. These are: The *Handbook of Operating Instructions*, the *Handbook of Service Instructions*, the *Handbook of Overhaul* (O/H) *Instructions*, and the *Illustrated Parts Breakdown* (IPB). These handbooks contain the condensed results of countless tests and checks made to assist the technician and operator in getting the best possible performance from the equipment. The handbooks are authorized for publication by the Chief of the Bureau of

Aeronautics and are printed in accordance with a prescribed arrangement.

All BuAer publications are assigned coded numbers; the first two numbers indicate the general subject classification. The first two numbers for handbooks on armament control systems are in the 11 series while 16 is the code for electronic handbooks.

The *Handbook of Operating Instructions* contains information pertaining to the operation of the specific equipment and also the necessary checks and adjustments required for obtaining good operating conditions. These books are divided into the following sections: A general description of the equipment, the operating procedures, the operating checks and adjustments, and provisions for emergency operation of the system.

The *Handbook of Service Instructions* provides information concerning the preparation for use and the maintenance of the specific equipment by Operational (Squadron), FASRon, or equivalent activities. The handbook is divided into seven sections as follows:

Section I, Description and Leading Particulars.—This section gives a description of the equipment and the general principles of its operation. Included in the section is information on the interchangeability of components and any special electrical or mechanical characteristics of the system or components.

Section II, Special Test Equipment and Special Tools.—Listed in this portion of the handbook are all necessary special test equipment and tools (including test racks) which are used for making complete bench test of the system or the components. Any instructions necessary for modifying the test equipment for some special use or for the fabrication of special testing harness are also found in this section.

Section III, Preparation for Use and Reshipment.—This section is divided systematically, showing the method by which the particular equipment should be handled from the moment it is received until it is ready for use by the operator. The section contains general information on uncrating and assembling the equipment on the test bench or in the aircraft, removing it from the aircraft, and recrating it for shipment. Detailed descriptions of cable fabrication and the connections of cables to the components are also included. Applicable data on any checks and adjustments required during installation of the equipment is found in this section.

Section IV, Theory of Operation.—A general description of the particular system is presented first, and this is followed by the detailed explanations of the individual circuits. The general description is usually given from the viewpoint of signal development, and block diagrams are used to trace the signal-development path.

Section V, Organizational and Operational Maintenance.—This section provides the instructions essential for the maintenance of the equipment and indicates the maintenance activities which perform it. Included are the preflight and postflight inspections and tests, the bench-test procedures, and the troubleshooting methods to be used by these activities.

Section VI, Field and FASRon Maintenance.—The instructions required for the servicing of the equipment at FASRon or Field maintenance levels are included in this portion. In addition to alinement and parts removal procedures, information is given for checking component functions by means of performance checks. Also contained in this section are systematic trouble isolation procedures which assist in localizing a defective part or component to a circuit or group of circuits, depending upon the nature of the equipment.

Section VII, Diagrams.—In this section are contained all the necessary diagrams for the maintenance and interconnection of the system. These include complete schematic, wiring, voltage, and resistance diagrams of the system or its components for use in trouble analysis. Also included are cabling charts for connection of the equipment components.

The *Handbook of Overhaul Instructions* provides detailed information for overhauling the electronic equipment and components for which it is issued. This includes such procedures as disassembly, cleaning, repair, recalibration, testing, and any other steps necessary for complete overhaul. The handbook is issued primarily to overhaul activities because the nature of the work described is beyond the capacities and facilities of the Squadron and FASRon maintenance activities.

The *Illustrated Parts Breakdown* contains detailed illustrations and listings of the components and parts of the equipment for which it is issued. The main value of this book for the technician is its usefulness when ordering parts for replacement purposes.

Revisions are prepared and distributed when it becomes necessary to modify the handbook. When properly entered, the revisions serve to keep the book an official source of the latest information applicable to the equipment. The available handbooks and the revisions are listed in the *NavAer Publications Index* and its supplements. By making periodic checks of these, it is possible to determine which revisions are current and should be included in the handbook.

Aircraft Armament Changes and Bulletins

Aircraft Armament Changes (AAC's) describe mandatory changes or modifications to specific items of armament equipment. An AAC is issued when a piece of equipment proves inadequate or unsatisfactory and a new item, or a modification of the old one, has been developed which will improve its performance. Aircraft Armament Changes are numbered consecutively as issued. A complete listing of all AAC's issued, together with the date of issue, those canceled, and those still in effect may be found in the Armament Section of the *NavAer Publications Index.*

Aircraft Armament Bulletins (AAB's) are issued for specific items of armament equipment in the same manner as AAC's. AAB's are also mandatory but are not generally issued for changes to equipment. These directives are for changes in procedures and methods of operation. Like armament changes, AAB's are numbered consecutively and listed in the *NavAer Publications Index.*

Electronic Material Bulletins and Changes

Electronic Material Bulletins and Electronic Material Changes are issued by the Chief of the Bureau of Aeronautics to all aeronautical activities. The purpose of these publications is to put into effect technical data concerning airborne electronic and electrical material.

Electronic Material Bulletins are technical instructions. They pertain to the operation, inspection, alinement, and maintenance procedures of the equipment.

Electronic Material Changes promulgate technical instructions necessary for the addition, removal, or replacement of a part; modification of circuit, etc. Modification of electronic material is normally limited to modification of parts, subassemblies, assemblies, components, or complete equipment, and interconnecting wiring. (Electronic Material Changes are not used for substitution of complete system.) The changes resulting from these instructions have negligible effects on the weight and balance of the aircraft or on the aircraft structure.

Electronic Material Bulletins and Electronic Material Changes specify the time at which compliance must be made to the instructions and also the manner in which it is to be made. These publications replace Technical Orders and Technical Notes insofar as electronics and electrical material are concerned.

Electronics Digest

The Naval Aviation Electronics Service Unit each month prepares and publishes the magazine, *Digest of U. S. Naval Aviation Electronics*, by direction of the Chief of the Bureau of Aeronautics. The *Digest* gives information on electrical and electronic equipment relative to operation, maintenance, installations and supply. This is an excellent source of information dealing with new equipment and new ideas on the older equipment. It gives the latest procedures for speeding the testing, calibrating, and alinement of equipment now in use as these methods are developed by the Electronics Service Unit and other activities. While a considerable portion of the *Digest* is devoted to equipment not directly concerning aviation fire control, it often contains valuable information for the AQ. Some editions are devoted exclusively to aviation armament and fire control.

BUREAU OF ORDNANCE PUBLICATIONS

Bureau of Ordnance Manual

The *Bureau of Ordnance Manual* sets forth overall policies, broad directives, and general information. The information and instructions contained in the manual are for the guidance of personnel involved in matters under the cognizance of the Bureau of Ordnance. Essentially general in nature, the manual may be used as an aid in obtaining detailed information.

Index of Ordnance Publications

The *Index of Ordnance Publications* (*Ordnance Pamphlet 0*) is a listing of all types of unclassified and confidential ordnance publications stocked for issue by the Bureau of Ordnance.

Part 1 of the *Index* comprises a numerical listing of all current publications and includes the following information concerning each publication: Type of publication, date of issue, security classification of material, and other pertinent information listed in the "remarks" column.

Part 1A is a listing by number and type of publication of all obsolete, canceled, and superseded publications.

Part 2, called the Subject Index, is an alphabetical listing of all publications by subject.

Ordnance Pamphlets

Ordnance Pamphlets (OP's), whether in "Preliminary" or final form, are basic publications dealing with specific ordnance equipment or providing instructions and data for fleet and field use. OP's are of two categories:

1. Equipment OP's: These provide instructions for ef-

fective use of specific ordnance equipment. Each major unit of an ordnance installation is covered by an OP containing applicable theory and description; operation, installation, assembly, maintenance, overhaul, and repair instructions; and safety precautions. An equipment OP is a general reference and maintenance manual for operating personnel. It is so written and indexed as to also serve as a reference book for instruction and training.

2. Specific subject OP's: These provide a central source of information relating to a specific ordnance subject.

All currently effective OP's are listed in numerical order in Part 1 of the *Index of Ordnance Publications*, and alphabetically by subject in Part 2 of the *Index*.

Ordnance Data

Ordnance Data (NavOrd OD's) contain routine test and inspection results. Installation and alinement data, parallax data, publications requirements lists, and ordnance equipment lists are normally provided in NavOrd OD's. As the OP's, they are listed in the *Index*. Ordnance Data often form an important source of information to the maintenance man.

REPORTS

The method of reporting defective material is determined by current BuAer and BuOrd Instructions. At the present time, the AQ may be concerned with three different reports in reporting failed or unsatisfactory aeronautical material. These three are: Failure or Unsatisfactory Report (FUR), Electronic Failure Report (EFR), and Report of Unsatisfactory Mechanical Aviation Ordnance Equipment (RUMAOE).

Briefly the difference in use between the three is:

1. The FUR is used to report failure when a faulty equipment, or a component or assembly has to be REPLACED by obtaining a NEW item from supply, and turning the old one in for repair or credit.

2. The EFR is used to report all routine electronics and

electrical failures in which an equipment, component, or assembly is to be repaired and then REINSTALLED.

3. The RUMAOE is used to report defective or unsatisfactory MECHANICAL components of Bomb Director Set AN/ASB-1 and Radar Set AN/APS-66.

Failure, Unsatisfactory, or Removal Report

Complete information on the Failure, Unsatisfactory, or Removal Report is found in BuAer Instruction NAVAER 00.58B. You will use this form for reporting defective or unsatisfactory aeronautical equipment, including aviation ordnance equipment, with the exceptions of electrical and electronic components, and mechanical components of Bomb Director Set AN/ASB/-1 and Radar Set AN/APS-66. The Bureau of Aeronautics has established this reporting procedure to permit statistical evaluation of the frequency of such unsatisfactory conditions.

The FUR form consists of eight sheets or forms separated by carbon paper to comprise a pad or set. The eight sheets are: Failure, Unsatisfactory, or Removal Report (1); File Copy (1); Documents for Returning Material (3); Memorandum Request for Material (2); and Tag (1). The forms are completed by use of a legible pencil, pen, or typewriter.

The FUR is the first sheet of the FUR set. When making out the FUR, an understanding of the failure can be increased by amplifying remarks. These remarks are added on the back of the FUR. The FUR then becomes an AMPFUR (amplified failure or unsatisfactory report). When in the opinion of the reporting activity the subject requires immediate remedial action, the report may be assigned priority as an URGENT AMPFUR. When in the opinion of the reporting activity the subject relates directly to flight safety, the report will be assigned priority as a FLIGHT SAFETY AMPFUR.

All AMPFUR's, URGENT AMPFUR's, and SAFETY-OF-FLIGHT AMPFUR's receive individual attention at the Bureau of Aeronautics. Regular FUR's are used for quantitative analysis.

It should be noted that the second sheet of the report, the the File Copy, is not an accountable document but serves only as a source of information for personnel preparing Stub Requisitions.

The third, fourth, and fifth sheets, the Documents for Returning Material, are used for the financial accounting of the returned material. It is used to accompany all turn-in items to the supporting supply facility.

The sixth and seventh sheets, Memorandum Requests for Material, are not accountable documents; however, they may be used as advance authority for immediate issuance of replacement material.

The last sheet, FUR tag, is secured to all turn-in items. The sheet is folded and inserted in a standard naval window envelope with the activity name, report serial number, and part stock number appearing in the window. By use of a grommet, the envelope is then wired to the turn-in part.

Electronic Failure Reports

Electronic Failure Reports are prepared and submitted for all failure or unsatisfactory conditions of electron tubes and electronic or electrical parts, equipments, or system. The purpose of these reports is to provide the bureau with up-to-date information on equipment failures and reliability. Complete information of these reports is found in BuAer Instructions NAVAER 00.58B.

These reports are normally filled out and signed by the person diagnosing the trouble or effecting the repair of the defective material. For defective airborne electronic material, one copy of the report is forwarded by the reporting activity, within seven days of the date of failure, to the Chief of the Bureau of Aeronautics.

A report must be submitted for each failure occurring, or upon determination that a part or tube is defective or unsatisfactory for any reason. In cases where two or more associated parts are found to be defective, and doubt exists as to which part is primarily at fault, each suspected part must be reported separately and reference made to all other reports of the associated failure. All reports of a multiple failure of the associated parts should then be fastened together to permit rapid evaluation.

For conducting reliability studies, data from the reports are transcribed by the Bureau to punched cards to permit automatic accounting machine processing, tabulation, and analyses of failure data. The analyses are utilized as a medium for improving reliability, performance, design, and maintenance of equipment and materials, and for contractor's study of failures and remedy of unsatisfactory conditions. Compiled data also serve as a guide for operational and supply activities to adjust maintenance support stock levels. In order for the failure reports to serve the above purposes, it is imperative that each and every failure or fault be reported, and that reports be complete in all details.

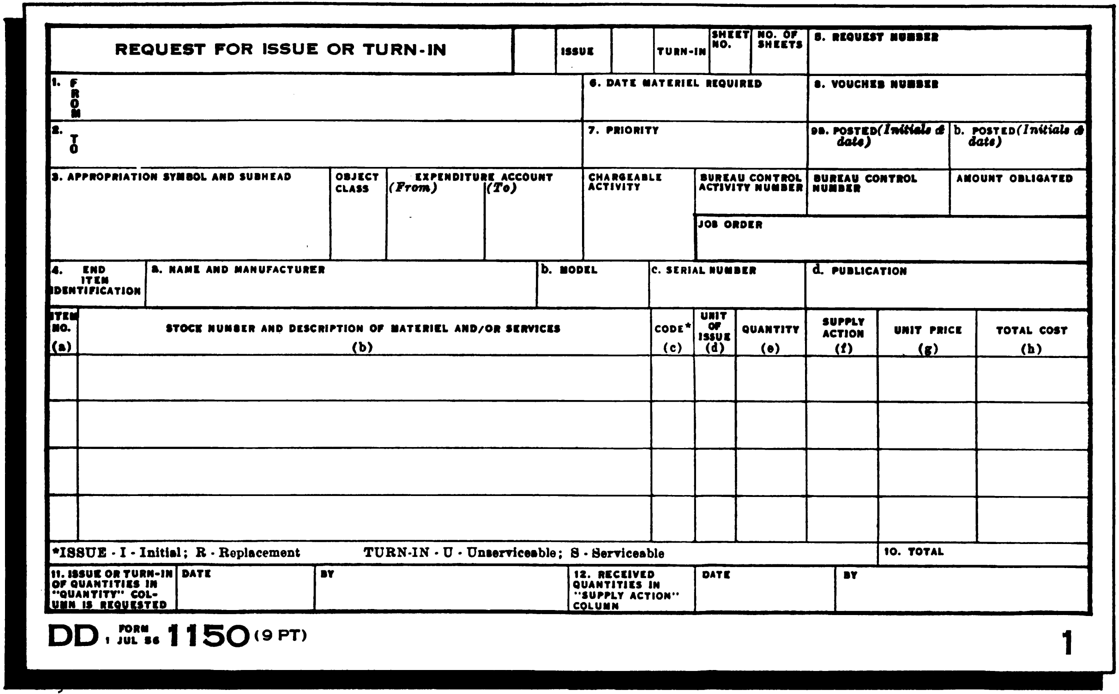
You are encouraged to submit any suggestion that might be of value in connection with failures. Information or data which the reporting activity consider may assist in evaluating the cause of the failure, or which may offer relief from additional failures, are desired. Photographs, drawings, sketches, samples, etc., may be submitted as enclosures to the basic report.

Unsatisfactory Mechanical Aviation Ordnance Equipment

The Report of Unsatisfactory Mechanical Aviation Ordnance Equipment is used for the mechanical components of Bomb Director AN/ASB–1 and Radar Set AN/APS–66. Three copies of each report are forwarded directly to the Chief, Bureau of Ordnance. Photographs, if applicable, may be submitted. Further details on the purpose and use of this form may be found in BuOrd Instruction 8600.6A.

REQUEST FOR ISSUE OR TURN-IN

Because all naval activities draw equipment from a central supply point, you can see why standardized requisition forms are used. Besides the standard forms covered here, there



REQUEST FOR ISSUE OR TURN-IN

ISSUE ☐ TURN-IN ☐

SHEET NO.

NO. OF SHEETS

5. REQUEST NUMBER

1. FROM

6. DATE MATERIEL REQUIRED

8. VOUCHER NUMBER

2. TO

7. PRIORITY

9a. POSTED (*Initials & date*)

b. POSTED (*Initials & date*)

3. APPROPRIATION SYMBOL AND SUBHEAD

OBJECT CLASS

EXPENDITURE ACCOUNT (*From*) (*To*)

CHARGEABLE ACTIVITY

BUREAU CONTROL ACTIVITY NUMBER

BUREAU CONTROL NUMBER

AMOUNT OBLIGATED

JOB ORDER

4. END ITEM IDENTIFICATION

a. NAME AND MANUFACTURER

b. MODEL

c. SERIAL NUMBER

d. PUBLICATION

ITEM NO. (a)	STOCK NUMBER AND DESCRIPTION OF MATERIEL AND/OR SERVICES (b)	CODE* (c)	UNIT OF ISSUE (d)	QUANTITY (e)	SUPPLY ACTION (f)	UNIT PRICE (g)	TOTAL COST (h)

*ISSUE - I - Initial; R - Replacement TURN-IN - U - Unserviceable; S - Serviceable

10. TOTAL

11. ISSUE OR TURN-IN OF QUANTITIES IN "QUANTITY" COLUMN IS REQUESTED

DATE

BY

12. RECEIVED QUANTITIES IN "SUPPLY ACTION" COLUMN

DATE

BY

DD FORM 1 JUL 56 1150 (9 PT)

1

Figure 14-1.—Form DD 1150, Request for Issue or Turn-in.

are numerous local type forms in use. These local forms are issued by local supply activities to simplify the process of requisitioning material. However, when local forms are used, the supply activity must complete standard forms on the items issued.

Defense Department Forms DD 1150 and DD 1150A, request for issue or turn-in, are used by aviation activities both ashore and afloat to requisition or turn in materials. (See fig. 14–1.) Form DD 1150 (white) is used to requisition materials and is prepared in multiple copies. Local requirements determine the number of copies to be prepared. Each class of material must be requisitioned on separate sets of forms. Form DD 1150A is used to turn in materials and is yellow in color. It also must be prepared in multiple copies with each set utilized for only one class of material.

PERFORMANCE RECORDS AND CHECKLISTS

Performance records are kept to show a continuous history of the performance and required maintenance of either a type or a particular piece of equipment. There are many times when these records prove of great value to the maintenance man. Occasionally, an Instruction will require that a performance record be kept because the equipment is comparatively new or of an experimental nature. These Instructions will usually include detailed information on the type, frequency, and entries to be used in the record. All aviation fire control equipment do not require performance records—it will depend upon the particular activity.

One of several systems may be used when it is desirable or necessary to keep a performance record. A record of the information obtained from the preflight and postflight checks plus the periodic checks may be entered in a ledger type logbook, a looseleaf type logbook, or the checklists themselves may be placed in a binder and thus become the record.

The ledger type records have the advantage that the pages are not easily lost or removed. Further, they will remain in consecutive order. However, they have the disadvantage that the pages cannot be removed and replaced when desired.

The looseleaf type records facilitate the removal and replacement of pages. Checklist performance records are usually kept in a looseleaf binder. Care must be taken to insure that the pages are not lost or placed in an incorrect order.

Since performance records are usually kept to fulfill a specific need, the entries of the record will contain this needed information. The records prove their worth only when properly kept. When kept up to date in accordance with instructions, they provide a valuable reference, they aid in maintenance and repair work, and they improve the quality and dependability of the equipment.

Periodic Checklists

Periodic maintenance inspections are performed on all aircraft and aircraft systems. To properly perform these inspections, maintenance activities, prepare checklists (or sheets). These lists itemize all components or assemblies to be inspected. Also, they usually provide a space next to the individual inspection for the initials of the person performing the inspection. The AQ3 will assist in the performance of these inspections by checking certain items pertaining to the fire control equipment. However, the extent of his work will depend on the type of organization to which he is assigned and the policies of the organization. These checklists are usually prepared from the *Handbook of Service Instructions*, and for newer aircraft from the *Handbook of Inspection Requirements.*

The new *Handbooks of Inspection Requirements* are composed of three parts. Part 1 contains general instructions, definitions, special inspections, replacement schedules, and a listing of applicable references. Part 2 is a master copy of the Daily and Preflight Inspection Check Sheet. Part 3 is a master copy of the Intermediate and Major Inspection Check Sheets, organized by systems, including entry spaced for additional work to be performed, discrepancies noted and corrected, and parts added and removed during the inspection.

Preflight inspection.—This inspection is performed prior to the first flight of the day, and is performed by a line maintenance crew. The inspection consists of checking the aircraft for flight preparedness by performing visual examination and operational tests to discover defects and maladjustments that, if not corrected, could cause accidents or aborted missions. The AQ3 can normally be expected to perform the visual inspections and make operational tests such as making operator's adjustments, reading and interpreting dials, built-in meters and cathode-ray-tube presentations.

Postflight inspection.—This inspection is performed on the line, as is the preflight, after the last flight of the day or more frequently when warranted by local conditions. This inspection is, basically, a combination of requirements for checking equipment that requires daily verification of satisfactory functioning, plus requirements that prescribe searching for defects that become apparent after the aircraft is flown. It is intended that evidence of chafing, leaks, and similar conditions be discovered and corrected during the postflight inspection to preclude progression of such a relatively minor problem to a state that would require major maintenance to remedy the deficiency. The postflight inspection is, therefore, an important function that should be performed with care. The AQ3 will normally perform similar duties on this inspection as listed under preflight inspection.

Intermediate inspection.—The intermediate inspection is, basically, a limited overall examination of the condition of the aircraft. The inspection includes certain requirements that are also applicable to preflight or postflight inspections, and it also includes requirements that must be fulfilled at periods occurring more frequently than major inspections. The statement of each requirement indicates how thorough the examination or test should be, and refers to any special tool or test equipment that is to be used. These inspections are usually performed at the following intervals:

1. The first intermediate inspection will normally become due at the expiration of 30 flying hours after the preceding major inspection.

2. The second intermediate inspection will normally become due at the expiration of 30 hours after the first intermediate inspection, normally 60 hours after the preceding major inspection.

3. The third intermediate inspection will normally become due at the expiration of the 30 flying hours after the second intermediate inspection, normally 90 hours after the preceding major inspection.

A CALENDAR intermediate inspection is performed in lieu of the first, second, or third intermediate inspection, when the aircraft has not accumulated 30 flying hours in the 60-day period since the last previous intermediate or major inspection.

Since additional tools and test equipment are required to perform the intermediate inspection, it is normally performed within the hangar spaces, thus giving ready access to power connections, etc. The AQ3 may be assigned to a check crew that will perform the aviation fire control portion of this inspection. Many of the items of the checklist may be performed by the AQ3 alone, while others will be under the supervision of a senior AQ. The more complex items will be accomplished by a senior AQ with the third class acting as his assistant.

MAJOR INSPECTION.—The major inspection is a thorough and searching inspection of the entire aircraft. The inspection includes certain requirements that are also applicable to preflight, postflight, and intermediate inspections. The thoroughness of the check required and special tools or test equipment to be used are indicated in the statement of each requirement. The major inspection will normally be performed at the expiration of 30 flying hours after the third intermediate inspection following the preceding major inspection. A CALENDAR major inspection is performed in lieu of a regular major inspection, when the aircraft does not accumulate 120 flying hours in the 180-day period since the previous major inspection.

The portions of the major inspections that the AQ3 will perform will be similar to those performed in the intermediate inspection. However, due to the greater scope of the major inspection, there will be a greater number of items to be checked and more items to be accomplished under supervision.

NOTE: During the inspections such items as cleaning, lubrication, etc. will be performed. These items are scheduled to insure their accomplishment at regular intervals, these intervals corresponding to the intervals between certain types of inspections.

EQUIPMENT WORK LOGS AND HISTORIES

Although there are many work flow methods in use, let us consider one typical method. In this method, when the preflight check is made, or when the pilots return from flight, a comprehensive form known as a "yellow sheet" is filled out. These yellow sheets are routed to the Maintenance Department Planning Office. Here "work orders" for all discrepancies noted are prepared, assigned priorities, and routed to the cognizant Division Office. A work order is prepared, numbered, and assigned for every specific check or task to be performed. Except for internal shop and test equipment upkeep and installation, no work may be performed by the shops without this written authority from the maintenance planning office.

As work orders arrive at the Division Office, they are entered on the Division Officer's Status Board. The board affords an overall picture for the Division of the condition of all aircraft assigned. From the Division Office the work order is routed to the appropriate shop. Here the assignment for performing the necessary work is made. Upon completion of the work, appropriate entries are made in the logs and the work order is returned to the maintenance office. Word is also passed to the Division Office for notation on the Status Board.

SHOP LOGS.—Most maintenance shops use a shop log to keep a record of work performed by the shop. The entries in this log usually consist of the serial number of the work order, the aircraft number, date, repairs completed, and man-hours involved. There is also a space for the person's name or initials who performs the necessary work, plus a space for the supervisor's initials. Normally the ledger type record book is used as the shop log.

Equipment work logs.—Equipment work logs, sometimes called bench logs, are used to keep a record of a specific type of system. This type of log is often used in conjunction with the shop logs. The majority of the identifying information is obtained for both logs from the work order. Whatever the preventive or corrective action taken is also entered in the logs. The entries for the equipment log may also contain the serial number of the equipment.

One of the advantages in the use of equipment logs is that the cause of recurring trouble may be detected and eliminated. Also modifications, alterations, field changes or any other maintenance information may be logged by specific type or piece of equipment. Thus, the end result is a maintenance history of the type or piece of equipment. The entries for this type of log are usually entered in a ledger type record book, although a looseleaf record may be kept.

Equipment histories.—Equipment histories may be kept by the logbook or the card methods. The logbook method would be essentially an equipment work log with the necessary entries to complete the history of the equipment.

A form that may be used and is readily available for a history card is NavShips 536—Electronic Equipment History Card. This is the basic maintenance history card for electronic equipment. It provides for recording failures and other pertinent information on electronic equipments. A separate card is filled in for each equipment or major component of larger equipments. The card is so designed that when it is properly filled in, the necessary information is readily available for partial completion of the Electronic Failure Report. The heading of the history card should be typed, but entries on the body may be either typed or written in ink or indelible pencil.

QUIZ

1. The system in use throughout the Navy for the issuance of directive-type releases is known as
    - a. Central Information Service
    - b. Navy Directives System
    - c. Joint Army-Navy Directive System
    - d. Navy Logistic System
2. An Instruction has permanent reference value and is effective until
    - a. it has been read and complied with
    - b. it becomes obsolete or outdated
    - c. the originator supersedes or cancels it
    - d. action before a certain date has been taken
3. A monthly periodical, which is an excellent information source of electrical and electronic maintenance, operation, installation, and supply, is the
    - a. *U.S. Naval Air Electronic News*
    - b. *Digest of U.S. Naval Aviation Electronics*
    - c. *U.S. Naval Air Electrical Digest*
    - d. *Aviation Electrical News, U.S. Navy*
4. The *Bureau of Aeronautics Manual* consists of
    - a. detailed information and instructions concerning aviation
    - b. a consolidated listing of all publications which pertain to aviation
    - c. a listing of past Notices and Instructions for information only
    - d. general policy information and instructions concerning matters under the cognizance of the Bureau of Aeronautics
5. The *Naval Aeronautic Publications Index* is divided into ________ main parts.
    - a. five
    - b. four
    - c. three
    - d. two
6. Instructions for ordering BuAer publications may be found in the
    - a. *Bureau of Aeronautics Manual*
    - b. Issuance Instructions, SecNav Instruction 5215.0
    - c. *NavAer Publications Index*
    - d. *Aircraft Maintenance Handbooks*

7. The *NavAer Publications Index* is issued
   a. semiannually, with quarterly revisions
   b. quarterly, with annual revisions
   c. annually, with semiannual revisions
   d. annually, with periodic revisions

8. The *Handbook of Maintenance Instructions* for a particular aircraft will contain ________________ sections.
   a. two
   b. four
   c. five
   d. ten

9. For each radar system, there are ________________ handbooks prepared.
   a. one
   b. three
   c. four
   d. five

10. The *Bureau of Ordnance Manual* contains
    a. detailed listing of all material under the cognizance of the Bureau of Ordnance
    b. all current TO's and TN's in effect at the time of issue
    c. overall policies, broad directives, and general information
    d. detailed instructions regarding procurement and maintenance of ordnance material

11. The *Handbook of Service Instructions* of specific electronic equipment is provided for use by
    a. operators
    b. squadron and FASRon activities
    c. FASRon and overhaul activities
    d. overhaul activities

12. Ordnance Pamphlets (OP's) are of two categories. These are
    a. operation OP's and maintenance OP's
    b. maintenance OP's and overhaul OP's
    c. operation OP's and specific equipment OP's
    d. specific equipment OP's and specific subject OP's

13. When a defective item must be turned in, so that a replacement may be obtained, the accompanying FUR report sheets are the
    a. FUR, MR, and the EFR
    b. FUR and the RM
    c. FUR, MR, and the Tag
    d. RM and the Tag

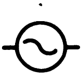
14. When a radar component is to be repaired and then reinstalled, the proper report to be made is the
   a. RUDM
   b. FUR
   c. RUMAOE
   d. EFR

15. The FUR form consists of ________________ sheets separated by carbon paper to comprise a set.
   a. two
   b. three
   c. eight
   d. five

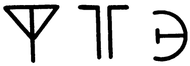
16. A limited overall examination of an aircraft is conducted during the
   a. major inspection
   b. postflight inspection
   c. intermediate inspection
   d. preflight inspection

APPENDIX I—ELECTRICAL SYMBOLS

AC SOURCE

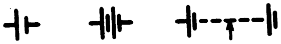


ANTENNA



GENERAL DIPOLE RADAR

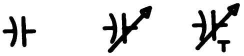
BATTERY



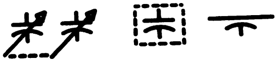
ONECELL MULTICELL TAPPED MULTICELL

(LONG LINE IS POSITIVE)

CAPACITOR



FIXED VARIABLE TRIMMER



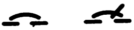
GANGED SHIELDED FEED THROUGH

(WHEN ELECTRODE IDENTIFICATION IS NECESSARY, CURVED ELEMENT REPRESENTS OUTSIDE ELECTRODE OF PAPER AND CERAMIC UNITS, NEGATIVE OF ELECTROLYTICS AND LOW POTENTIAL ELECTRODE OF FEED THROUGH.)

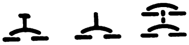
CHASSIS

(CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL)

CIRCUIT BREAKER

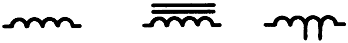


AUTOMATIC SWITCH

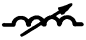


PUSH PULL PUSH GANGED

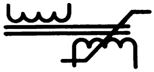
COIL



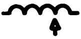
GENERAL MAGNETIC CORE TAPPED



ADJUSTABLE OR VARIABLE

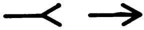


SATURABLE CORE INDUCTOR OR REACTOR (UPPER COIL IS DC WINDING)

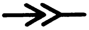


ADJUSTABLE

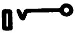
CONNECTOR



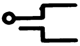
FEMALE MALE PIN CONTACTS



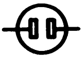
ENGAGED PIN CONTACTS



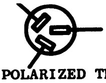
JACK



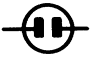
PLUG



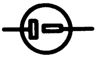
OUTLET OR CONNECTOR WITH FEMALE CONTACTS



POLARIZED THREE CONDUCTOR CONNECTOR

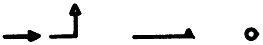


OUTLET OR CONNECTOR WITH MALE CONTACTS

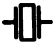


POLARIZED TWO CONDUCTOR CONNECTOR

CONTACT

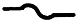


GENERAL MOMENTARY SWITCH



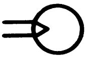
CRYSTAL, PIEZOELECTRIC

FUSE



GROUND

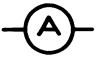
LAMP



PILOT OR INCANDESCENT

APPENDIX I—ELECTRICAL SYMBOLS—Continued

METER



A - AMMETER

CRO - OSCILLOSCOPE

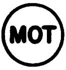
G - GALVANOMETER

MA - MILLIAMMETER

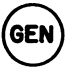
VA - MICROAMMETER

V - VOLTMETER

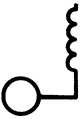
MOTOR AND GENERATOR



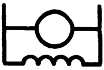
MOTOR



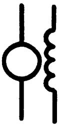
GENERATOR



SERIES



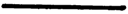
SHUNT

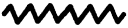


SEPARATELY EXCITED

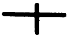
PATH

CONDUCTIVE

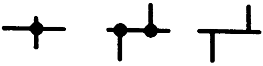




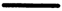
AIR OR SPACE



NO CONNECTION

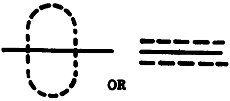


CONNECTIONS

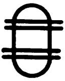


SINGLE

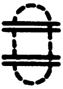
CONDUCTOR



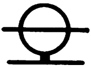
SHIELDED SINGLE CONDUCTOR



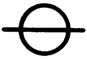
MULTI CONDUCTOR CABLE



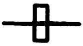
SHIELDED CABLE



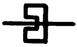
COAXIAL CABLE



CIRCULAR WAVEGUIDE

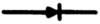


RECTANGULAR WAVEGUIDE



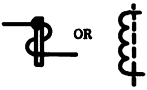
RIDGED WAVEGUIDE

RECTIFIER

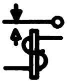


METALLIC RECTIFICER METALLIC RECTIFIER; CRYSTAL DIODE; ELECTROLYTIC RECTIFIER; (ARROW SHOWS DIRECTION OF FORWARD OR EASY CURRENT AS INDICATED BY DC AMMETER)

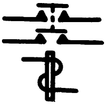
RELAY



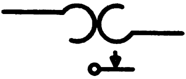
RELAY COIL
(DOT INDICATES INNER END OF WINDING)



SPDT CONTACTS

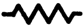


TWO--CIRCUIT

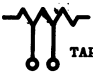


THERMAL

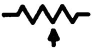
RESISTOR



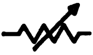
BASIC



TAPPED

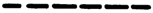


ADJUSTABLE



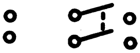
VARIABLE

SHIELDING

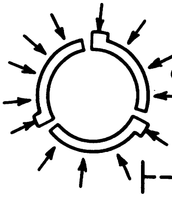


SWITCH

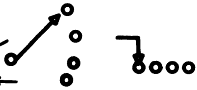
BASIC



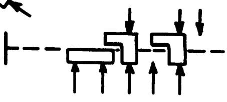
DPDT



WAFER



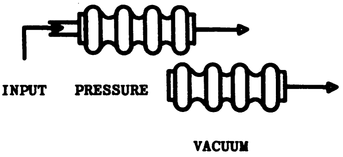
SELECTOR



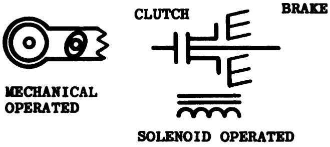
SLIDE

APPENDIX II—MECHANICAL SYMBOLS

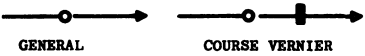
BELLOWS



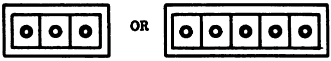
BRAKES



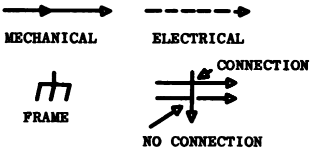
CLAMPS (OFFSETTING)



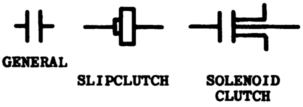
COUNTERS



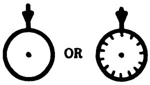
CONNECTIONS



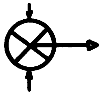
CLUTCHES



DIALS

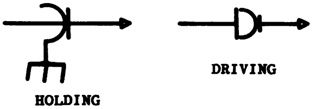


DIFFERENTIAL

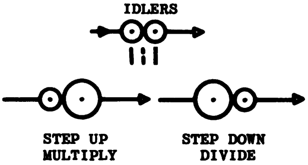


THE CROSS IN THE CENTER REPRESENTS THE SPIDER. THE ARROWS POINTING INWARD REPRESENT INPUTS. THE ARROW POINTING OUTWARD REPRESENTS THE OUTPUT.

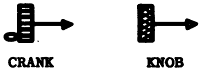
FRICTION



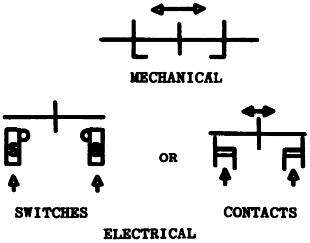
GEAR RATIO



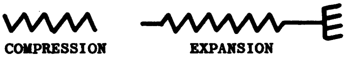
HAND INPUTS



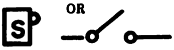
LIMIT STOPS



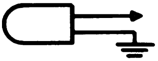
SPRINGS



SWITCH



TEMPERATURE ELEMENT



APPENDIX III

AVIATION FIRE CONTROL SYMBOLS

The following symbols (notations) are used throughout the text in discussions of the airborne fire control problem and the equipment used to solve the problem.

VELOCITY AND ACCELERATION:

Symbol	*Definition*
a	Acceleration.
d	Distance covered in time "t."
F	Force. $F=\frac{mV^2}{\text{radius}}$
f	Frequency in cycles per sec.
g	Acceleration due to gravity. ($g=32$ ft/sec/sec.)
r. p. s.	Revolutions per second.
r. p. m.	Revolutions per minute.
t	Time.
V	Velocity.
α	(Alpha)—Angular acceleration. $\left(\alpha=\frac{\omega}{t}\right)$
θ	(Theta)—Angular distance covered. $(\theta=2\pi ft=\omega t)$
π	(Pi)—Constant 3.14159. $2\pi=6.28$ (approx.)
ω	(Omega)—Angular velocity. $\omega=2\pi f$

GUN FIRING PROBLEM:

Symbol	*Definition*
G	Present position of gun platform.
G_f	Actual position of gun platform when projectile strikes target.
G'_f	Future position of gun platform.
r	Present range.
r_f	Future range.
T	Present position of target.
T_f	Future position of target.
t_f	Time of flight of projectile.
t_L	Lost time of flight.
V_G	Velocity of gun platform.
V_o	Muzzle velocity of projectile.
V_T	Velocity of target.

GUN FIRING PROBLEM—Continued

Symbol	*Definition*
Λ	(Lambda)—Total lead angle.
Λ_A	Total azimuth lead angle.
Λ_E	Total elevation lead angle.
Λ_b	Ballistic lead angle.
Λ_{bA}	Azimuth component of ballistic lead angle.
Λ_{bE}	Elevation component of ballistic lead angle.
Λ_k	Kinematic lead angle.
Λ_{kA}	Azimuth component of kinematic lead angle.
Λ_{kE}	Elevation component of kinematic lead angle.

BOMBING PROBLEM:

Symbol	*Definition*
A	Impact point of a bomb in a vacuum.
a	Angle of depression.
B	Impact point of bomb in air.
H	Altitude of bombing plane above target level.
O—O'	Line of flight of bombing plane, during time of flight of bomb in a vacuum.
R	Range of target along the horizontal.
r	Bomb trail.
S	Slant range.
t_f	Time of flight or time of fall of the bomb.
V	Bombing plane's true airspeed.
V_c	Closing speed between bombing plane and target. Ground speed of bombing plane when target is stationary.
V_T	Velocity of target.
W	Velocity of wind.
θ	(Theta)—Drift angle.
ϕ	(Phi)—Range angle of target.

APPENDIX IV

AN NOMENCLATURE SYSTEM

The AN letter-number system is used to identify the various kinds and models of electronic apparatus employed by the Army, the Navy, and the Air Force. Separate types of designations are used for complete installations of a particular equipment and for major components of the device. The basic designation for a complete instalation is considered first.

An indicator for a complete installation begins with the letters AN. (The letters AN are an abbreviation for Army-Navy, but does not mean that the Army or Navy utilizes the equipment.) This is followed by a slant bar and a three-letter group. The three letters of the second group give the general nature of the installation, the type of equipment, and the purpose of the equipment respectively. Following the three-letter group is a number which indicates the specific model of the equipment.

An example of a basic designation is AN/APG–30. The letters following the slant bar have the meanings given in table 1.

Using the example AN/APG–30, the symbols are interpreted as follows: AN signifies a complete installation. In the three-letter group, the first letter, A, in the first or "Installation" column, indicates airborne equipment. The second letter, P, is in the "Type of Equipment" column; therefore, it indicates radar equipment. The letter G in the "Purpose" column refers to fire control or search light directing equipment. Examination of the *Handbook of Operating or Service Instructions* will give further information on the exact purpose of the equipment.

The number 30 following the letters of the second group is the model number of the set. If the basic model is modified, the new model is given an additional letter such as A, B, or C, following the model number. For example, AN/APG–30A is a modification of the basic AN/APG–30 model. The next modification is labeled AN/APG–30B.

When the system just described is applied to subassemblies or major components of the complete installation, the designation is formed by replacing the letters AN with a letter-number group which indicates the type and model of component in question.

Table 1.—Set or equipment indicator letters.

Installation	Type of equipment	Purpose
A—Airborne (installed and operated in aircraft).	A—Invisible light, heat radiation.	A—Auxiliary assemblies (not complete operating sets).
B—Underwater mobile, submarine.	B—Pigeon.	B—Bombing.
D—Pilotless carrier.	C—Carrier.	C—Communications (receiving and transmitting).
F—Fixed.	D—Radiac.	D—Direction finder.
G—Ground, general ground use (includes two or more ground installations).	E—Nupac (nuclear protection and control).	E—Ejection and/or release.
K—Amphibious.	F—Photographic.	G—Fire control or searchlight directing.
M—Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment).	G—Telegraph or teletype.	H—Recording and/or reproducing (graphic, meteorological, and sound).
P—Pack or portable (animal or man).	I—Interphone and public address.	M—Maintenance and test assemblies (including tools).
S—Water surface craft.	J—Electromechanical (not otherwise covered).	N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach and landing).
T—Ground, transportable.	K—Telemetering.	Q—Special or combination of purposes.
U—General utility (includes two or more general installation classes, airborne, shipboard, and ground).	L—Countermeasures.	R—Receiving, passive detecting.
V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, such as tanks).	M—Meteorological.	S—Detecting and/or range and bearing.
W—Water; surface and undersurface.	N—Sound in air.	T—Transmitting.
	P—Radar.	W—Control.
	Q—Sonar and underwater sound.	X—Identification and recognition.
	R—Radio.	
	S—Special types (magnetic, etc.) or combination of types.	
	T—Telephone (wire).	
	V—Visual and visible light.	
	W—Armament (peculiar to armament, not otherwise covered).	
	X—Facsimile or television.	

Table 2 gives the component indicator, family name, and examples of use. An example of this type of component is:

AS–629/APQ–50—Antenna, complex No. 629, part of radar set AN/APQ–50.

A unit that is not a part of any complete installation but may be used with many installations also is found in table 2. An example of this type of unit is:

TS–352/U—Test item, multimeter No. 352 for general utility use.

Table 2.—Component indicators.

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
AB	Supports, Antenna	Antenna mounts, mast bases, mast sections, towers, etc.

Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
AM	Amplifiers	Power, audio, interphone, radio frequency, video, electronic control, etc.
AS	Antennae, Complex	Arrays, parabolic type, masthead, etc.
AT	Antennae, Simple	Whip or telescopic, loop, dipole, reflector, etc.
BA	Battery, primary type.	B batteries, battery packs, etc.
BB	Battery, secondary type.	Storage batteries, battery packs, etc.
C	Controls	Control box, remote tuning control, etc.
CG	Cable Assemblies, RF.	RF cables, wave guides, transmission lines, etc. with terminals.
CK	Crystal kits	A kit of crystals with holders.
CM	Comparators	Compares two or more input signals.
CN	Compensators	Electrical and/or mechanical compensating, regulating, or attenuating apparatus.
CP	Computers	A mechanical and/or electronic mathematical calculating device.
CR	Crystals	Crystal in crystal holder.
CU	Couplers	Impedance coupling devices, directional couplers, etc.
CV	Converters (electronic).	Electronic apparatus for changing the phase, frequency, or from one medium to another.
CW	Covers	Cover, bag, roll, cap, radome, nacelle, etc.
CX	Cable Assemblies, Non-RF.	Non-RF cables with terminals, test leads, also composite cables of RF and non-RF conductors.
CY	Cases and Cabinets	Rigid and semirigid structure for enclosing or carrying equipment.
DA	Load, Dummy	RF and non-RF test loads.
DT	Detecting Heads	Magnetic pickup device, search coil, hydrophone, etc.
DY	Dynamotors	Dynamotor power supply.
F	Filters	Band-pass, noise, telephone, wave traps, etc.
FR	Frequency Measuring Devices.	Frequency meters, tuned cavity, etc.

Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
G	Generators, Power	Electrical power generators without prime movers. (See PU & PD.)
HD	Air Conditioning Apparatus.	Heating, cooling, dehumidifying, pressure, vacuum devices, etc.
ID	Indicators, Non-Cathode-Ray Tube.	Calibrated dials and meters, indicating lights, etc. (See IP.)
IL	Insulators	Strain, stand-off, feed-through, etc.
IM	Intensity Measuring Devices.	Includes SWR gear, field intensity and noise meters, slotted lines, etc.
IP	Indicators, Cathode-Ray Tube.	Azimuth, elevation, panoramic, etc.
J	Junction Devices	Junction, jack and terminal boxes, etc.
KY	Keying Devices	Mechanical, electrical, and electronic keyers, coders, interrupters, etc.
MD	Modulators	Device for varying amplitude, frequency or phase.
ME	Meters, Portable	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MF	Magnets or Magnetic Field Generators.	Magnetic tape or wire eraser, electromagnet, permanent magnet, etc.
MK	Miscellaneous Kits	Maintenance, modification, etc., except tool and crystal. (See CK, TK.)
ML	Meteorological Devices.	Barometer, hygrometer, thermometer, scales, etc.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified. Do not use if better indicator is available.
O	Oscillators	Master frequency, blocking, multivibrators, etc. (For test oscillators, see SG.)
OA	Operating Assemblies	Assembly of operating units not otherwise covered.
OS	Oscilloscope, Test	Test Oscilloscopes for general test purposes.
PP	Power Supplies	Nonrotating machine type such as vibrator pack, rectifier, thermoelectric, etc.

Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
PU	Power Equipments	Rotating power equipment except dynamotors. Motor-generator, etc.
R	Receivers	Receivers, all types except telephone.
RE	Relay Assemblies	Electrical, electronic, etc.
RF	Radio Frequency Component.	Composite component of RF circuits. Do not use if better indicator is available.
RG	Cables, RF, Bulk	RF cable, wave guides, transmission lines, etc. without terminals.
RT	Receiver and Transmitter.	Radio and radar transceivers, composite transmitter and receiver, etc.
SA	Switching Devices	Manual, impact, motor driven, pressure operated, etc.
SG	Signal Generators	Test oscillators, noise generators, etc. (See O.)
SM	Simulators	Flight aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
T	Transmitters	Transmitters, all types except telephone.
TD	Timing Devices	Mechanical and electronic timing devices, range device, multiplexers, electronic gates, etc.
TF	Transformers	Transformers when used as separate items.
TG	Positioning Devices	Tilt and/or train assemblies.
TK	Tool Kits	Miscellaneous tool assemblies.
TL	Tools	All types except line construction.
TN	Tuning Units	Receiver, transmitter, antenna, tuning units, etc.
TR	Transducers	Magnetic heads, phono pickups, sonar transducers, vibration pickups, etc.
TS	Test Items	Test and measuring equipment not otherwise included; boresighting and alinement equipment.
TV	Tester, Tube	Electronic tube tester.
TW	Tapes and Recording Wires.	Recording tape and wire, splicing, electrical insulating tape, etc.
U	Connectors, Audio and Power.	Unions, plugs, sockets, adapters, etc.

Table 2.—Component indicators—Continued

Comp. ind.	Family name	Examples of use (not to be construed as limiting the application of the component indicator)
UG	Connectors, RF	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
ZM	Impedance Measuring Devices.	Used for measuring Q, C, L, R or PF, etc.

APPENDIX V

ANSWERS TO QUIZZES

CHAPTER 1

INTRODUCTION TO AVIATION FIRE CONTROL

1. d.
2. c.
3. d.
4. a.
5. b.
6. d.
7. a.
8. c.
9. d.
10. c.
11. c.
12 b.
13 a.
14. b.
15. a.
16. d.
17. b.
18. c.
19. d.
20. b.
21. b.
22. d.
23. a.
24. d.
25. a.

CHAPTER 2

BALLISTICS AND TRAJECTORY FACTORS

1. b.
2. d.
3. d.
4. a.
5. b.
6. a.
7. a.
8. d.
9. b.
10. c.
11. b.
12. d.
13. a.
14. c.
15. c.
16. a.
17. b.
18. a.
19. d.
20. c.
21. b.
22. c.
23. b.
24. c.
25. a.

CHAPTER 3

THE FIRE CONTROL PROBLEM

1. d.
2. a.
3. b.
4. c.
5. a.
6. b.
7. d.
8. c.
9. a.
10. b.
11. c.
12. b.
13. d.
14. c.
15. c.
16. a.
17. b.
18. b.
19. c.
20. a.
21. c.
22. d.
23. b.
24. a.
25. b.
26. a.
27. c.
28. d.
29. b.

CHAPTER 4

AIRCRAFT NONCOMPUTING SIGHTS

1. c.
2. a.
3. c.
4. b.
5. d.
6. a.
7. c.
8. a.
9. d.
10. b.
11. d.
12. a.
13. c.
14. d.
15. a.
16. b.
17. d.
18. c.
19. b.
20. c.
21. a.
22. d.
23. b.
24. d.
25. a.

CHAPTER 5

AIRCRAFT COMPUTING SIGHTS

1. a.
2. c.
3. d.
4. b.
5. c.
6. a.
7. c.
8. d.
9. a.
10. b.
11. c.
12. d.
13. a.
14. b.
15. c.
16. a.
17. d.
18. d.
19. a.
20. a.
21. b.
22. a.
23. d.
24. c.
25. d.

CHAPTER 6

ARMAMENT CONTROL SYSTEMS

1. b.
2. c.
3. d.
4. c.
5. b.
6. a.
7. c.
8. b.
9. a.
10. c.
11. b.
12. a.
13. b.
14. b.
15. b.
16. b.
17. c.
18. a.
19. d.
20. a.
21. c.
22. a.
23. c.
24. c.
25. b.
26. b.

CHAPTER 7

AIRCRAFT TURRET CONTROL

1. b.
2. a.
3. c.
4. b.
5. d.
6. b.
7. d.
8. c.
9. a.
10. d.
11. d.
12. d.
13. d.
14. b.
15. c.
16. a.
17. d.
18. b.
19. c.
20. a.
21. b.
22. d.
23. c.
24. d.
25. d.

CHAPTER 8

BOMB DIRECTORS

1. b.
2. d.
3. c.
4. a.
5. b.
6. d.
7. c.
8. a.
9. b.
10. c.
11. d.
12. d.
13. b.
14. d.
15. b.
16. a.
17. d.
18. c.
19. a.
20. c.
21. b.
22. d.

CHAPTER 9

ELECTRICAL EQUIPMENT

1. b.
2. c.
3. d.
4. a.
5. c.
6. c.
7. d.
8. a.
9. b.
10. b.
11. d.
12. a.
13. a.
14. c.
15. b.
16. d.
17. a.
18. b.
19. c.
20. c.
21. b.
22. d.
23. a.
24. a.
25. a.

CHAPTER 10

ELECTRICAL MAINTENANCE

1. c.
2. c.
3. b.
4. a.
5. c.
6. d.
7. b.
8. d.
9. a.
10. b.
11. b.
12. b.
13. a.
14. a.
15. b.
16. c.
17. a.
18. d.
19. c.
20. c.
21. a.
22. c.

CHAPTER 11

MECHANICAL MAINTENANCE

1. c.
2. c.
3. a.
4. b.
5. b.
6. d.
7. a.
8. b.
9. c.
10. b.
11. a.
12. a.
13. b.
14. b.
15. b.
16. c.
17. a.
18. d.
19. b.
20. a.
21. a.
22. a.
23. d.
24. a.
25. d.

CHAPTER 12

BORESIGHTING

1. a.
2. d.
3. d.
4. b.
5. d.
6. c.
7. c.
8. a.
9. c.
10. b.
11. c.
12. a.
13. d.
14. c.
15. d.

CHAPTER 13

SAFETY PRECAUTIONS

1. a.
2. c.
3. d.
4. c.
5. b.
6. b.
7. b.
8. d.
9. d.
10. c.

CHAPTER 14

PUBLICATIONS, REPORTS, LOGS, AND FORMS

1. b.
2. c.
3. b.
4. d.
5. d.
6. c.
7. d.
8. d.
9. c.
10. c.
11. b.
12. d.
13. d.
14. d.
15. c.
16. c.

APPENDIX VI

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION FIRE CONTROL TECHNICIANS (AQ)

Rating Code No. 6520

General Service Rating

Scope

Aviation Fire Control Technicians test, maintain, and repair aviation fire control equipment; inspect, clean, lubricate, and perform operational tests and adjustments of sights, bomb directors, armament control systems, and turret control systems; remove and reinstall major components and subassemblies; calibrate, repair, and make performance measurements and computing tests of computers, gyros, optional components, and fire control radars; make detailed mechanical, electrical, and electronic casualty analysis; boresight and aline sights, computers, fire control radars, and aircraft weapons; make authorized repairs and adjustments to associated test equipment.

Emergency Service Rating

AVIATION FIRE CONTROL TECHNICIANS F (Aircraft Armament Control Systems), Rating Code No. 6522------------------------------ AQF

Test, maintain, and repair aviation fire control equipment (excluding bomb directors); inspect, clean, lubricate, and perform operational tests of optical gun sights, armament control systems, and turret control systems; remove and reinstall major components, assemblies, subassemblies, and detailed parts; calibrate, repair, and make performance measurements and computing tests of computers, gyros, optical components, and armament control radars; make detailed mechanical, electrical, and electronic casualty analysis; boresight and aline optical gunsights, computers, armament control radars, and aircraft weapons; make authorized repairs and adjustments to associated test equipment.

AVIATION FIRE CONTROL TECHNICIANS B (Bomb Director), Rating Code No. 6521--- AQB

Test, maintain, and repair bomb director systems; inspect, clean, lubricate, and perform operational tests and adjustments of bomb director systems (including optical components thereof); remove and reinstall major components, assemblies, subassemblies, and detailed parts; calibrate, repair, and make performance measurements and computing tests of computers, gyros, optical components, and bomb director radars; make detailed mechanical, electrical, and electronic casualty analysis; boresight and aline sights, computers, and bomb director radars; make authorized repairs and adjustments to associated test equipment.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see *Manual of Navy Enlisted Classifications*, NavPers 15105 (Revised), codes AQ–7900 through AQ–7999.

Qualifications for Advancement in Rating

Qualifications for advancement in rating	*Applicable rates*		
	AQ	AQF	AQB
100 PRACTICAL FACTORS			
101 OPERATIONAL			
1. Demonstrate under simulated conditions the rescue of a person in contact with an energized electrical circuit, resuscitation of a person unconscious from electrical shock, and treatment for electrical burns	3	3	3
2. Energize, secure, set operating controls, make operator's adjustments and read and interpret dials, built-in meters, and cathode ray tube presentations on:			
*a. Aircraft armament control systems	3	3	--
*b. Bomb director systems	3	--	3
102 MAINTENANCE AND/OR REPAIR			
1. Select and use hand tools and small portable power tools provided for maintenance and repair of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
2. Make electrical connections and splices, including soldered joints	3	3	3

*Where terms "aircraft armament control systems" and "bomb director systems" are used in the qualifications items, these systems are defined in terms of the scopes of emergency service ratings.

Qualifications for advancement in rating	*Applicable rates*		
	AQ	AQF	AQB
102 MAINTENANCE AND/OR REPAIR—Continued			
3. Operate the following test equipment:			
a. Voltmeter	3	3	3
b. Ammeter	3	3	3
c. Ohmmeter	3	3	3
d. Multimeter	3	3	3
e. Megger	3	3	3
f. Tube tester	3	3	3
g. Oscilloscope	3	3	3
h. Vacuum tube voltmeter	3	3	3
4. Perform operational tests, make external adjustments and isolate casualties to major components of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
5. Test and replace relays, plugs, lamps, fuses, switches, electron tubes, jacks, cables, and wiring	3	3	3
6. Draw and interpret schematic diagrams of electrical circuits; read and interpret wiring diagrams of electrical circuits found in technical maintenance publications; identify electronic and mechanical symbols	3	3	3
7. Identify capacitors, resistors, and wiring by standard color coding systems	3	3	3
8. Test aviation fire control circuits for continuity, short circuits, and grounds between major components, and report results	3	3	3
9. Use block diagrams and mechanical drawings to locate and identify major components and subassemblies of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
10. Inspect and clean commutators and slip ring assemblies; inspect and replace brushes	3	3	3
11. Lubricate and clean components of the following systems in accordance with technical maintenance publications:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3

Qualifications for advancement in rating	AQ	AQF	AQB
102 MAINTENANCE AND/OR REPAIR—Continued			
12. Remove, reinstall, inspect and test for correct installation major components and subassemblies of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
13. Boresight and aline aircraft sights of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
14. Operate the following test equipment:			
a. Signal generator	2	2	2
b. Frequency meter	2	2	2
c. Sweep generator	2	2	2
15. Perform tests, adjustments, and repairs necessary for proper operation of power supplies, including analysis of casualties in rectifiers, regulators, and filter circuits	2	2	2
16. Perform tests, adjustments, and repairs necessary for proper operation of electromechanical computers, including analysis of casualties in voltage amplifiers, power amplifiers, phase detectors and amplitude modulators	2	2	2
17. Perform tests, adjustments, and repairs necessary for proper operation of electromechanical servo mechanisms and synchro circuits including:			
a. Zeroing of synchros, servomotors, and potentiometers	2	2	2
b. Gain, phase, and balancing adjustments	2	2	2
18. Test electronic and electromechanical computers for alinement; replace basic fire control mechanisms and circuit components; make alinement adjustments	2	2	2
19. Perform computing and rate tests of electronic and electromechanical computers, using calculated values and tolerances found in technical maintenance publications	2	2	2
20. Test and replace resistors, capacitors, inductors, plug-in units, potentiometers, synchros, servomotors, shafts, and gearing	2	2	2

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	AQF	AQB
102	MAINTENANCE AND/OR REPAIR—Continued			
	21. Draw and interpret schematic diagrams of electronic circuits; read and interpret wiring diagrams of electronic circuits found in technical maintenance publications	2	2	2
	22. Test aviation fire control electronic circuits for continuity, short circuits, and grounds; measure electrical quantities, such as voltage, current, power, frequency, and phase angle, and compare with established values; trace signals, using an oscilloscope; determine wave forms and compare with established or required forms	2	2	2
	23. Effect field changes in accordance with instructions and diagrams to:			
	a. Aircraft armament control systems	2	2	--
	b. Bomb director systems	2	--	2
	24. Operate the following test equipment:			
	a. Range calibrator	1	1	1
	b. Spectrum analyzer	1	1	1
	c. RF wattmeter	1	1	1
	d. Wavemeter	1	1	1
	e. Echo box	1	1	1
	25. Perform tests, adjustments, and repairs necessary for proper operation of radar components, including analysis of casualties in transmitters, receivers, synchronizers, modulators, indicators, and antenna systems, used in:			
	a. Aircraft armament control systems	1	1	--
	b. Bomb director systems	1	--	1
	26. Make performance measurements, calibrations, and adjustments to bring to optimum performance:			
	a. Complete airborne intercept and turret systems	1	1	--
	b. Complete bombing systems	1	--	1
	27. Boresight and aline fire control radars and optical devices associated with:			
	a. Aircraft weapons	1	1	--
	b. Bombing systems	1	--	1

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	AQF	AQB
102	MAINTENANCE AND/OR REPAIR—Continued			
	28. Determine proper operation of and replace klystrons, magnetrons, T/R and AT/R boxes, crystal mixers, wave guide sections, pressurizing systems, and antennas	1	1	1
	29. Lubricate and perform authorized adjustments to gyroscopes used in:			
	a. Aircraft armament control systems	1	1	--
	b. Bomb director systems	1	--	1
	30. Evaluate for correct operation, make authorized repairs and calibrations to:			
	a. Aircraft armament control test equipment	C	C	--
	b. Bomb director test equipment	C	--	C
	31. Evaluate repaired, overhauled, or newly installed aircraft armament control systems for proper and secure installation and optimum equipment performance	C	C	--
	32. Evaluate repaired, overhauled, or newly installed bomb director systems for proper and secure installation and optimum equipment performance	C	--	C
	33. Analyze results of boresighting and alinement tests, computing and rate tests, and records of performance for alinement and computing accuracy within weapons systems	C	C	C
	34. Analyze electrical and electronic test data; reduce data and effect indicated corrections to aviation fire control equipment; compare values; set or determine values to be used for measuring responses	C	C	C
103	ADMINISTRATIVE AND/OR CLERICAL			
	1. Complete entries in equipment work logs, equipment histories, and performance records of:			
	a. Aircraft armament control systems	3	3	--
	b. Bomb director systems	3	--	3

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	AQF	AQB
103	ADMINISTRATION AND/OR CLERICAL—Continued			
	2. Prepare and complete entries in the following:			
	a. Aviation fire control equipment periodic check lists	3	3	3
	b. Stub requisition forms	3	3	3
	c. Failure and unsatisfactory reports (FUR)	3	3	3
	d. Standard Aircraft Inventory Logs	2	2	2
	3. Obtain part and stock numbers from available technical supply publications for obtaining replacement material; requisition, store, and account for materials and spare parts	2	2	2
	4. Evaluate completed equipment check lists, shop and equipment work logs, equipment histories, and equipment failure reports; review stub requisitions for spare parts, tools, and materials to be drawn from shop storeroom	1	1	1
	5. Prepare job orders and work requests	1	1	1
	6. Take, record, and report inventory of equipment, spare parts, tools, test equipment, and materials in shop and shop storeroom	1	1	1
	7. Prepare reports covering status and condition of aircraft armament control systems, associated test equipment, and shop work accomplished	C	C	--
	8. Prepare reports covering status and condition of bomb director systems, associated test equipment, and shop work accomplished	C	--	C
	9. Evaluate inventories in terms of shop requirements and prepare requisitions to replenish stock or to obtain new items for shop storeroom	C	C	C
200	EXAMINATION SUBJECTS			
201	OPERATIONAL			
	1. Safety precautions to be observed in working with or near electrical, electronic and ordnance equipment	3	3	3
	2. Effects of electrical shock, method of resuscitation of a person unconscious from electrical shock, treatment for electrical burns	3	3	3

	Qualifications for advancement in rating	Applicable rates		
		AQ	AQF	AQB
201	OPERATIONAL—Continued			
	3. Purpose of the following operator's controls and adjustments:			
	a. Intensity	3	3	3
	b. Focus	3	3	3
	c. Centering	3	3	3
	d. Receiver gain	3	3	3
	e. Receiver tuning	3	3	3
	f. Dial lighting	3	3	3
	g. Light filters	3	3	3
	h. Azimuth and elevation controls	3	3	3
	i. Range strobe control	3	3	--
	j. Ranging throttle grip	3	3	--
	4. Interpretation of dial settings into minutes, degrees, yards, or mils	3	3	3
	5. Types and purposes of cathode ray tube presentations of radars used in aviation fire control	3	3	3
	6. Effects of own aircraft motion and target motion in:			
	a. Air-to-air and air-to-ground gunnery and rocketry	3	3	--
	b. Horizontal, dive, toss and loft bombing	3	--	3
	7. Effects of principal factors influencing trajectories of projectiles, including:			
	a. Gravity	3	3	3
	b. Air resistance	3	3	3
	c. Wind	3	3	3
	d. Angle of departure (initial angle of inclination) of projectile	3	3	3
	e. Initial velocity	3	3	--
	f. Rotation of projectile	3	3	--
	g. Self-propelling force of rockets and missiles	3	3	--
	8. Graphic resolution of vectors representing relative motion in and across line of sight	3	3	3

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	AQF	AQB
201	OPERATIONAL—Continued			
	9. Types and functions of equipment used in aviation fire control, including:			
	a. Armament control directors, and computers	3	3	3
	b. Fire control radars	3	3	3
	c. Noncomputing sights	3	3	--
	d. Computing sights	3	3	--
	e. Turret control equipment	3	3	--
	f. Bomb directors	3	--	3
	g. Armament control systems	3	3	--
	10. Systems of assigning "AN" designations, marks and mods, and Aero designations to identify components of:			
	a. Aircraft armament control systems	3	3	--
	b. Bomb director systems	3	--	3
	11. Graphic resolution of vectors representing relative motion and trajectory	2	2	2
	12. Analytical solution of vectors representing relative motion and trajectory	1	1	1
	13. Functional relationships among aircraft weapons; components of complete:			
	a. Airborne intercept and turret systems, and other aircraft equipment supplying data to or receiving data from these systems	1	1	--
	b. Bombing systems and other aircraft equipment supplying data to or receiving data from these systems	1	--	1
	14. Analysis of interior ballistics, exterior ballistics, and relative motion as applied to aviation fire control problems	C	C	--
	15. Analysis of exterior ballistics and relative motion as applied to aviation bombing problems	C	--	C
	16. Operating characteristics of:			
	a. Airborne intercept and turret equipment	C	C	--
	b. Airborne bombing equipment	C	--	C
	17. Operating characteristics of aircraft weapons controlled by:			
	a. Aircraft armament control systems	C	C	--
	b. Bomb director systems	C	--	C

Qualifications for advancement in rating	*Applicable rate*		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR			
1. Types and purposes of hand tools and small portable power tools used in maintenance and repair of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
2. Methods of making electrical connections and splices, including soldering materials used	3	3	3
3. Function of and operating procedures in using the following:			
a. Voltmeter	3	3	3
b. Ammeter	3	3	3
c. Ohmmeter	3	3	3
d. Multimeter	3	3	3
e. Megger	3	3	3
f. Tube tester	3	3	3
g. Vacuum tube voltmeter	3	3	3
h. Oscilloscope	3	3	3
4. Operating principles of voltmeter, ammeter, and ohmmeter (but not vacuum tube voltmeter), including:			
a. D'Arsonval meter movement	3	3	3
b. Shunts and multipliers	3	3	3
c. Use of thermocouples and rectifiers in a-c meters	3	3	3
5. Meanings of mechanical, electrical, and electronic symbols used in schematic diagrams of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
6. Interpretation of schematic diagrams and wiring diagrams of electrical circuits	3	3	3
7. Units of electrical measurement, including:			
a. Ampere	3	3	3
b. Volt	3	3	3
c. Ohm	3	3	3
d. Watt	3	3	3
e. Volt-ampere	3	3	3
f. Cycle	3	3	3
g. Henry	3	3	3
h. Farad	3	3	3
i. Ampere-turn	3	3	3
j. Prefixing of mega, kilo, milli, and micro	3	3	3

Qualifications for advancement in rating	*Applicable rates*		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR—Continued			
8. Meaning of:			
a. Conductors and insulators	3	3	3
b. Phase	3	3	3
c. Frequency	3	3	3
d. Power factor	3	3	3
e. Self and mutual inductance	3	3	3
f. Reactance	3	3	3
g. Impedance	3	3	3
h. Lines of force	3	3	3
i. Field intensity	3	3	3
j. Flux density	3	3	3
k. Permeability	3	3	3
l. Hysteresis and eddy current	3	3	3
9. Function of the following in electrical circuits:			
a. Resistors	3	3	3
b. Rheostats and potentiometers	3	3	3
c. Solenoids	3	3	3
d. Inductors	3	3	3
e. Capacitors	3	3	3
f. Fuses	3	3	3
g. Switches	3	3	3
h. Reactors	3	3	3
i. Transformers	3	3	3
j. Relays	3	3	3
10. Component parts of motors, generators, and alternators; application of laws of magnetism to electrical rotating machinery	3	3	3
11. Relationship of resistance, temperature, and current in a conductor	3	3	3
12. Relationship of the length and cross-sectional area to the resistance of a conductor	3	3	3
13. Calculation of current, voltage, and resistance in d-c series and parallel circuits containing not more than four elements	3	3	3
14. Relationship of current, voltage, and impedance in a-c circuits	3	3	3
15. Relationship of resistance, inductance, and capacitance in a-c circuits	3	3	3

Qualifications for advancement in rating	*Applicable rates*		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR—Continued			
16. Lubricants and cleaning solutions used in maintenance of:			
a. Aircraft armament control systems	3	3	--
b. Bomb director systems	3	--	3
17. Methods of cleaning commutators and slip ring assemblies and precautions to be followed	3	3	3
18. Types, construction, and operating principles of aircraft sights; procedures for boresighting aircraft sights	3	3	3
19. Standard color coding systems for resistors, capacitors, and wiring	3	3	3
20. Function of major components of radars, including transmitters, receivers, synchronizers, modulators, indicators, and antenna systems, used in:			
a. Aircraft armanent control systems	3	3	--
b. Bomb director systems	3	--	3
21. Function of and operating procedures in using the following:			
a. Signal generator	2	2	2
b. Frequency meter	2	2	2
c. Sweep generator	2	2	2
22. Operating principles of vacuum tube voltmeter	2	2	2
23. Effects of meter sensitivity in circuit voltage measurement	2	2	2
24. Interpretation of schematic diagrams and wiring diagrams of electronic circuits	2	2	2
25. Calculation of current, voltage, phase angle, frequency, impedance, and resonance in a-c series and parallel circuits containing not more than four elements	2	2	2
26. Relationship of reluctance, flux, and magnetomotive force in a-c and d-c magnetic circuits	2	2	2
27. Meaning of:			
a. Gain	2	2	2
b. Feedback	2	2	2
c. Bias, cut-off, and grid current	2	2	2
d. Electron tube characteristic curves	2	2	2
e. Electron tube constants	2	2	2
f. Class A, AB, B, and C operation	2	2	2
g. Nonlinear, frequency, and phase distortion	2	2	2

Qualifications for advancement in rating	*Applicable rates*		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR—Continued			
28. Function of electron tubes, including:			
a. Application of electron tubes to rectification, amplification, oscillation, and wave shaping	2	2	2
b. Function of elements in diodes, triodes, tetrodes, and pentodes	2	2	2
c. Types and functions of gas-filled tubes and cathode ray tubes	2	2	2
29. Methods of coupling:			
a. Resistance (R–C networks)	2	2	2
b. Impedance (R–C–L networks)	2	2	2
c. Transformer	2	2	2
d. Direct	2	2	2
30. Operating principles of:			
a. Rectifiers: Half-wave, full-wave, bridge	2	2	2
b. Filter circuits	2	2	2
c. Regulators	2	2	2
d. Amplifiers: Voltage, power	2	2	2
e. Diode detectors	2	2	2
f. Amplitude modulators	2	2	2
g. Limiters	2	2	2
h. Cathode followers	2	2	2
i. Differentiators	2	2	2
j. Integrators	2	2	2
31. Functions of gyroscopes used in:			
a. Aircraft armament control systems	2	2	—
b. Bomb director systems	2	—	2
32. Function and operating principles of electro-hydraulic servomechanisms	2	2	2
33. Characteristics and use of synchros and servo motors; methods of setting to electrical zero; purpose of gain, phase, and balancing adjustments	2	2	2
34. Function and application of basic fire control mechanisms in solving the aviation fire control problem	2	2	2
35. Function of electronic and mechanical analogue circuits in aircraft computers	2	2	2
36. Operating principles of oscilloscope	2	2	2

Qualifications for advancement in rating	Applicable rates		
	AQ	AQF	AQB
202 MAINTENANCE AND/OR REPAIR—Continued			
37. Operating principles of:			
a. Cathode-ray tubes	2	2	2
b. Tuned coupling circuits	1	1	1
c RF amplifiers	1	1	1
d. IF amplifiers	1	1	1
e. Video amplifiers	1	1	1
f. Oscillators: Tuned-grid, Hartley, Colpitts, TPTG, crystal-controlled, electron-coupled	1	1	1
g. Clippers	1	1	1
h. AGC circuits	1	1	1
i AFC circuits	1	1	1
j. Blocking oscillators	1	1	1
k. Trigger circuits and multivibrators	1	1	1
l. Sawtooth generators	1	1	1
m. Peakers	1	1	1
n. Clampers	1	1	1
38. Function of and operating procedures in using the following:			
a. Range calibrator	1	1	1
b. Spectrum analyzer	1	1	1
c. RF wattmeter	1	1	1
d. Wavemeter	1	1	1
e. Echo box	1	1	1
39. Application of oscilloscopic wave form analysis to location of circuit malfunctions	1	1	1
40. Loading effects of test equipment on critical circuits, such as oscillators, tanks and wave shaping	1	1	1
41. Purpose and methods of making:			
a. Microwave power measurements	1	1	1
b. Sensitivity tests	1	1	1
c. Measurements of frequency spectrum of pulsed signals	1	1	1
d. Calibration measurements of range circuits	1	1	1

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	AQF	AQB
202	MAINTENANCE AND/OR REPAIR—Continued			
	42. Types and functions of:			
	a. Wave-guide sections	1	1	1
	b. Coaxial cables	1	1	1
	c. T/R and AT/R tubes	1	1	1
	d. Klystrons	1	1	1
	e. Magnetrons	1	1	1
	f. Crystal mixers	1	1	1
	43. Operating principles and characteristics of rate and stabilizing gyros	1	1	1
	44. Characteristics and construction of boresighting fixtures and target boards	1	1	1
	45. Circuitry and characteristics of standard electronic test equipment	C	C	C
	46. Relation of tube characteristics and tube constants to electronic circuitry	C	C	C
	47. Operating principles of:			
	a. Magnetic amplifiers	C	C	C
	b. Wave guides and coaxial cables	C	C	C
	c. T/R and AT/R tubes	C	C	C
	d. Klystrons	C	C	C
	e. Magnetrons	C	C	C
	f. Crystal mixers	C	C	C
	48. Radiation characteristics of parabolic and lens antennas	C	C	C
203	ADMINISTRATIVE AND/OR CLERICAL			
	1. Types of forms and records used in maintenance and repair of:			
	a. Aircraft armament control systems	3	3	--
	b. Bomb director systems	3	--	3
	2. Types of entries and information recorded in the following:			
	a. Aviation fire control equipment periodic check lists	3	3	3
	b. Stub requisitions forms	3	3	3
	c. Failure and unsatisfactory reports (FUR)	3	3	3
	d. Standard Aircraft Inventory Logs	2	2	2

	Qualifications for advancement in rating	*Applicable rates*		
		AQ	AQF	AQB
203	ADMINISTRATIVE AND/OR CLERICAL—Continued			
	3. Types of information pertinent to aviation fire control equipment contained in publications and instructions furnished by technical bureaus and manufacturers, including:			
	a. Aircraft Service Changes; handbooks of service instructions, handbooks of operation instructions; Ordnance Publications; Ordnance Data; Ordnance Circular Letters and Ordnance Alterations	3	3	3
	b. Allowance Lists; parts catalogs; Aviation Circular Letters; Electronic Material Bulletins and Changes	2	2	2
	4. Procedure for obtaining replacement parts, tools, test equipment, and materials for use within the shop	1	1	1
	5. Procedures for accounting for aviation fire control equipment, maintaining control of inventories and work flow, reporting equipment status and work accomplished	C	C	C
300	PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER			
	Aviation Fire Control Technicians advance to Warrant Aviation Ordnance Technician and/or to Limited Duty Officer, Aviation Ordnance. As an alternate, Aviation Fire Control Technicians advance to Warrant Aviation Electronics Technicians and/or to Limited Duty Officer, Aviation Electronics.			

INDEX

AFCS, 145–146, 188–245, 251–274
  Mk 6, 189–208, 251–255
    components, 191–202
    controls, operating, 202–204
    maintenance, 204–208
  Mk 6 Mod 3, 208–212
    operation, 210–212
    ranging, 208–210
  Mk 16, 212–238, 255–256
    components, 212–226
    controls, 226–232
    maintenance, 232–238
  Mk 21, 238–245, 273–274
    components, 239–243
    controls, 243–244
Aircraft armament changes and bulletins, 575
Aircraft turret control systems, 309–342
  all-weather, 324–342
    block diagram, 326–329
    components, 329–333
    maintenance, 342
    operating controls, 337–342
    operation, modes of, 333–337
    principles of operation, 325–326
  optical sight (Mk 18), 309–324
    block diagram, 312–315
    components and functional operation, 315–319
    controls, 320–323
    maintenance, 323–324
    principles of operation, 309–312
All-weather aircraft turret control system, 324–342
Amplifier Mk 53 Mod 0, 174–176
Armament control systems, 249–303
  all-weather system, 285–295
    block diagram, 285–287
    controls, purpose and use, 292–295
    director, 290–291
    flight data computer, 291–292
    radar, function of, 287–290
  missile guidance system, 295–303
    block diagram, 297–301
    controls, purpose and use, 301–303
    maintenance, 303
  visual-director system, 262–285
    AFCS Mk 21, 273–274
    block diagram, 262–264
    maintenance, 281–285
    radar components and functions, 268–273
    radar, modes of operation, 264–268
    radar operation and controls, 274–281
  visual-disturbed reticle, 250–262
    block diagram, ARO radar and AFCS Mk 6, 251–255
    block diagram, ARO radar and AFCS Mk 16, 255–256
    maintenance, 260–262
    radar, function of, 255–258
Artificial respiration, 566
Aviation fire control:
  bureaus responsible for, 4–5
  history of, 1–4

Aviation fire control—Continued
  introduction, 1
  technician, duties and responsibilities of, 6–20
  terminology, 5
Aviation Fire Control Technician:
  billets, 10–14
  duties and responsibilities, 6–9
    as a leader, 14–15
    supervisory, 9
  knowledge and skills needed, 17–18

Ballistics, 24–55
  effects on trajectory, 27–55
    air density, 30–33
    airspeed, 35–37
    angle of departure, 46–48
    gravity, 28–30
    muzzle velocity, 33–35
    rotation of projectile, 39–41
    self-propelling force of rockets, 48–53
    temperature, 37–39
    wind, 41–46
  information, 53–55
    methods of obtaining, 53–54
    presentation by graphs, 54–55
  interior, 24–47
Bomb directors, 347–387
  dive and glide, 351
  high level, 369–381
  level bombing, 347–351
  loft, 352–353
  low level, 354–368
  skip, 352
  toss, 352, 381–387
  types, 347
Bombing, 98–111
  dive, 107, 351
  high level, 98–105, 369–381
  loft, 110–111, 352–353
  low level, 105–107, 354–368
  methods of, 98
  toss, 108–109, 352, 381–383
Bombsight Mk 23, 355–362
Boresighting 537–551
  fixed system, 544–545
    alinement and harmonization, 545–549
    sequence, 544–545
  methods of, 543–544
  theory of, 537–544
    purpose, 537–538
    terms, 538–542
  turret system, 550–551
  types of, 542–543

Cables and connectors, 417–426
  moistureproofing, 439–441
  shielding and bonding, 436–439
  splicing, 439
  tying and lacing, 435–436
Circuit breakers and fuses, 394–399
Clutches, magnetic, 516–517
Collimating lenses, 138–139
Computers, 219–222
  Mk 86, 219–222
  Mk 87, 222
Converters:
  Mk 32, 240–241
  range data Mk 31, 208–209
Crimping, 429–433

Dive bombing, 107, 351

Electrical equipment, 391–441
  connectors and cables, 417–426
  fuses and circuit breakers, 394–399
  maintenance technique, 426–441
    cable splicing, 439
    crimping, 429–433
    moistureproofing, 439–441
    safety wiring, 433–435
    shielding and bonding, 436–439
    soldering, 426–429
    tying and lacing, 435–436

Electrical equipment—Continued
  relays, 404–410
  rheostats and potentiometers, 410–417
  solenoids, 391–394
  switches, 399–404
Electronic Digest, 576–577
Electronic material bulletins and changes, 576
Equipment work logs and histories, 587–588

Fire control. (*See* Aviation fire control.)
Fire control problem, 61–111
  air-to-air, 88–91
  bombing problem, 98–111
    (*See also* Bombing.)
  future target position, 85–88
  kinematic and ballistics lead angles, addition of, 94–97
  kinematic lead angles, graphic resolution of, 91–94
    three-dimensional case, 93–94
    two-dimensional case, 91–93
  phases of:
    acquisition, 61–63
    identification, 63–64
    ranging, 64–68
    tracking, 68–73
  pursuit and collision curves, 73–82
  relative motion concept, 82–85
Fuses and circuit breakers, 394–399

Gunsight Mk 18, 309–324
Gyroscope, principles of, 517–524

Handbooks:
  aircraft maintenance, 572
  equipment, 572–575
High level bombing, 98–105, 369–381
Hooke's joint, 524–526

***I**ndex, Naval Aeronautic Publications*, 571
Instructions and notices, 569–571

Kinematic and ballistics lead angles, addition of, 94–97
Kinematic lead angles, 91–94

Lenses, 129–140
  collimating, 138–139
  compound, 133–134
  magnification, 132–133
  types, 129–132
  use in fire control, 139–140
Light, 116–129
  behavior of, 118–121
  nature of, 116–118
  reflection of, 121–124
  refraction of, 124–129
Loft bombing, 110–111, 352–353
Low level bombing, 105–107, 354–368

Maintenance, 446–532
  electrical, 446–486
    megger, use of, 458–460
    meters and tests, 446–458
      continuity, 453–454
      ground, 454–455
      resistance, 457–458
      shorts, 455
      voltage, 456–457
    motors and generators, 472–486
    oscilloscope, 466–472
    tester, tube, 461–465
    tube testing, 460–461
  mechanical, 490–532
    basic devices, 493–515
    cleaning and lubrication, 526–532
    gyroscope, principle of, 517–524
    Hooke's joint, 524–526
    magnetic clutch, 516–517
    tools, portable, 490–493

Manuals:
  - *Bureau of Aeronautics*, 571
  - *Bureau of Ordnance*, 577

Mechanisms, basic, 493–515
  - cams, 506–509
  - coupling devices, 495–496
  - differentials, 503–506
  - gears, 496–500
  - limit stops, 502–503
  - multipliers, 509–515
  - shafts and bearings, 494–495
  - worm and worm wheel, 501–502

Megger, use of, 458–460

Meters, 446–453
  - multimeters, 448–449
  - review of, 446–448
  - use of, 449
  - vacuum tube voltmeter, 450–452

Mk 6 AFCS, 189–208, 251–255

Mk 6 Mod 3 AFCS, 208–212

Mk 16 AFCS, 212–238, 255–256

Mk 21 AFCS, 238–245, 273–274

Motors and generators, 472–486
  - disassembly, 472–473
  - inspecting and cleaning, 473–477
  - lubrication, 477–479
  - testing, 479–483
  - troubleshooting, 483–486

Optical sight system (computing) (Mk 18), 309–324

Optics, 116–140
  - mirrors, 122–124
  - prisms, 127–129
  - telescope, 136–138

Oscilloscope, 466–472

Performance records and check-lists, 583–587

Potentiometers and rheostats, 410–417

Publications:
  - BuAer:
    - Aircraft Armament Changes and Bulletins and Changes, 575
    - Electronic Material Bulletins and Changes, 576
    - *Electronics Digest*, 576–577
    - handbooks, 572–575
    - *Manual*, 571
    - *Publications Index*, 571
  - BuOrd:
    - *Data*, 578
    - *Manual*, 577
    - *Pamphlets*, 577–578
  - equipment work logs and histories, 587–588
  - Instructions and Notices, 569–571
  - performance records and check-lists, 583–587
  - reports, 578–581
  - request for issue or turn-in, 581–583

Radar AN/APA–16, 362–368

Radar, ARO, 250–258
  - function, 255–258
  - controls, 259–260

Ranging, 64–68, 189
  - radar, 67–68, 189, 208–209
  - stadiametric, 64–67, 189, 209–210
  - throttle grip, 200–202

Reflector plates, 143, 151–153, 160–164, 178, 204

Relays, 404–410

Reports—(FUR), (EFR), (RUMAOE), 578–581

Request for issue or turn-in, 581–583

Reticules, 142–143, 149–150, 155–157, 170, 181–182, 193–195

Rheostats and potentiometers, 410–417

Safety precautions, 555–566
  electronic, 558–566
    antennas, 564
    aviation fire control equipment, 564–566
    general, 560–563
    tubes, cathode ray, 563–564
  machinery, 558
  portable tools, 556–557
  responsibility, 555
Safety wiring, 433–435
Shock, electric, 566
Sights, 146–245, 309–324
  computing, 188–245
    Mk 18, 309–324
Sights—Continued
  development of, 140–146
  noncomputing, 146–183
    Mk 1 system, 176–183
    Mk 6 Mod 1, 167–176
    Mk 8, 146–155
    Mk 20 Mod 0, 155–160
    Mk 20 Mod 4, 160–166
Soldering, 426–429
Solenoids, 391–394
Suggestions for study, 18–20
Switches, 399–404

Toss bombing, 108–109, 352
Tube tester, 461–465

U. S. GOVERNMENT PRINTING OFFICE: 1957 O—417900